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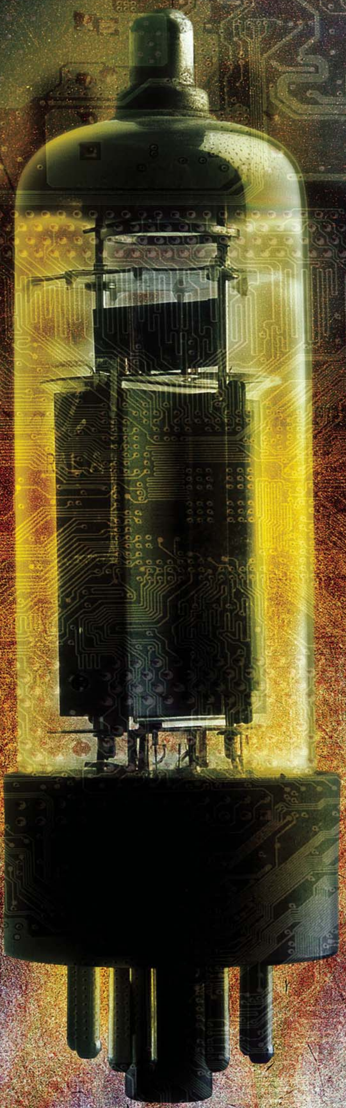

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NUTS AND VOLTS

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PROJECTS and FEATURES

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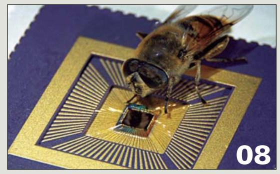
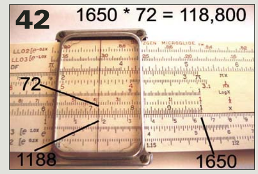
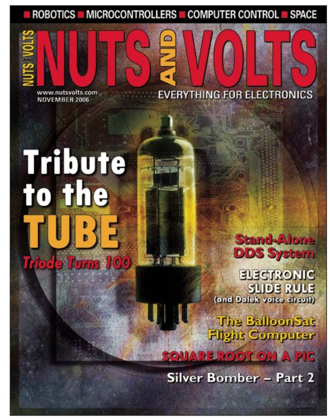




ON THE COVER ...

TRIBUTE TO THE TUBE:
TRIODE TURNS 100



COLUMNS

DEPARTMENTS

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READER FEEDBACK

DIGGIN' THE DIOS

The Dios microcomputer articles are very worthwhile, and Michael Simpson does a good job of putting out info that can be really used and things that can be built. I find this stuff more interesting than articles based on a preprogrammed micro and board type project that you have to buy from one supplier. Anyway, keep up the real *Nuts & Volts!*

Terry King

MORE KUDOS FOR SIMPSON ARTICLES

I would just like to say I have enjoyed *Nuts & Volts* magazine very much. I have been an electronics technician for about 15 years. I was introduced to Mike Simpson through your articles. It was through an advertisement in this magazine that I learned about his Athena microcontrollers and used his free software to write my first program. It was because of his products that I was able to start using the PICs that I read about for years. I would be interested in seeing more articles using the Athena and various other microcontrollers available from the Kronos website.

His articles take you through diverse paths in the microcontroller world. They range from health and fitness to building your own test equipment. I would like to see more.

Glen Koshinsky

Michael Simpson will be doing an upcoming series using X10, along with other cool Control-Your-World projects, so stay tuned! — Ed.

HEATSINKS STILL HOT

Thomas Ernst's letter paralleling 7805 regulators in the August Reader Feedback is interesting, but I see problems. According to the data sheet, the output voltage tolerance of the 78xx series regulators is about 4%. Unless the 7805's are matched, it appears that the 7805 with the highest output voltage will supply most of the output current, and will be overloaded. Assume three 7805s — A, B, and C — connected in parallel. Their outputs are 4.97 volts, 5.00 volts, and 5.02 volts, respectively. C will output 5.02 volts, which is above the output voltage of A and B. Therefore, A and B will shut down in an attempt to bring the output voltage down to their internal "setting," and all the output current will be from A.

His other suggestion, using two or three pass transistors, also has problems. When pass transistors are paralleled, it is usually necessary to connect a small resistor in series with the emitter of each transistor to equalize the current in the transistors. These resistors result in slightly lower output voltage and slightly poorer regulation. Also, there is a voltage drop in the base/emitter junction of the transistor, usually about 0.6 volts, and 5.6 volt regulators (for a final output of five volts) are hard to find. (This last problem can be solved by placing a forward-biased silicon diode between the GND terminal of the 7805 and the actual circuit ground; the voltage drop in the diode is about the same as the voltage drop in the base/emitter junction.)

However, the worst problem with pass transistors is that you lose the over-current, over-heating, and short circuit protection that is built into the 7805.

To me, using a heatsink is the best option.

Bill Stiles

HAPPY WITH LIFE (SUB)

Many years ago, I picked up a copy of *Nuts & Volts* at Hatry's in Hartford, CT. The offer was a lifetime subscription and I got to place an ad. Well I did, and offered a two-meter ham transceiver. So, for all these years you have kept up your end of the bargain. I am thankful and impressed that you kept your word.

Martin De Filippo
Wethersfield, CT

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EVERYTHING FOR ELECTRONICS

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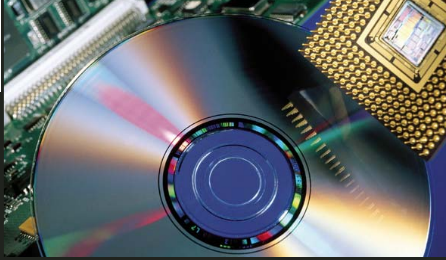


TECH KNOWLEDGEY 2006

EVENTS, ADVANCES, AND NEWS

■ BY JEFF ECKERT

ADVANCED TECHNOLOGY

LED "GREEN GAP" CLOSING

PHOTO COURTESY OF RENSSELAER, C. WETZEL, AND M. ZHU.

■ Rensselaer researchers aim to improve the efficiency of green LEDs.

It's no secret that LEDs are much more efficient light sources than incandescent and fluorescent devices, but you need a mix of red, green, and blue to generate white light. Unfortunately, the technology behind green LEDs has never been quite up to snuff. It is known that green LEDs can be produced by adding indium to the gallium nitride materials that compose blue LEDs, but the materials used so far have been inefficient, resulting in green devices that are too dim to be used in room illumination. But researchers at the Rensselaer Polytechnic Institute (**www.rensselaer.edu**) have come up with a concept that could lead to a practical LED for lighting homes and offices, and they recently received a $1.8 million grant from the US Dept. of Energy to assist in its development.

They plan to focus on the piezoelectric effect by which some materials produce an electrical field when pressure is applied. By controlling this effect, Prof. Christian Wetzel and colleagues hope to develop a process to make higher-intensity green LEDs that convert electricity into light more efficiently. The project is part of the DOE's Solid-State Lighting Program, which calls for the development of technologies that are more energy efficient, durable, and cost competitive by 2025.

VIDEO CAMERAS EMULATE BUG EYES

PHOTO COURTESY OF THE UNIVERSITY OF ADELAIDE.

■ A parking lot as seen by a conventional camera vs. a fly's brain.

Whether you are operating a surveillance camera or just trying to catch the shadow detail on Aunt Nellie's face as she blows out her birthday candles, you will often run into a problem that is inherent in standard digital cameras: they use a single average light setting to control the brightness of the image. This doesn't work so well in scenes having both very bright and very dim areas, and you end up losing shadows or highlights. Animals' eyes tend to do a better job of it, as the individual cells can adjust to different parts of the image. Now, Dr. Russell Brinkworth, a research fellow at Australia's University of Adelaide (**www.adelaide.edu.au**) has shown that it is possible to determine exactly how animal eyes work and to reproduce the process using computer software and hardware. "By learning from the insect world, we will be able to create video cameras that can resolve detail in light and dark, detect moving objects, rapidly compress and transmit video at incredible speed, and detect and measure the speed of very small objects moving in the distance," he noted.

In fact, his software has already been used to enhance existing video, and the intent is to write the software into a chip and merge it with existing technology. It would sit between the sensors and digital converter to automatically enhance the video quality. No commercial entity has signed up as a partner so far, but Brinkworth revealed that the US Air Force has been supportive, so whether the concept will end up in millions of camcorders or buried in a top secret military program is anyone's guess.

RECORD MAGNETIC FIELDS GENERATED

If you happen to have a steel plate in your head, you may want to avoid the National High Magnetic Field Laboratory's Pulsed Field Facility at the Los Alamos National Laboratory (**www.lanl.gov/mst/nhmfl**). In the continuing pursuit of a magnet capable of generating a 100-tesla magnetic field (a long-standing goal of magnet designers and researchers worldwide), scientists have set a new world's record. Earlier this year, the Field Facility staff commissioned an outer set of coils for a massive magnet being designed and assembled there, at which time the coil produced a peak magnetic field intensity of 35 tesla (T) within the coil's 225-millimeter dia. bore. This is significant because of the record large volume in which the 35-T field was produced and because man-made fields of this strength have never before been produced without the use of highly destructive, explosives-driven technologies. Earlier this summer, they actually reached 80T 10 times with a pulsed-magnet prototype before experiencing a fault.

When completed, the magnet will consist of a combination of seven coil sets weighing nearly 18,000 lbs and will be powered by a 1,200-megajoule

motor generator. It will be able to provide hundreds of milliseconds of unprecedented magnetic field intensity, primarily to study how various materials behave under such extreme conditions. The Earth's magnetic field at the equator, by the way, has been measured at a mere 31T. Interestingly enough, the Earth's field has a tendency to reverse itself every 200,000 years or so, but your compass should remain operational for a while.

COMPUTERS AND NETWORKING

ORNL COMPUTER HITS 54 TFLOPS

PHOTO COURTESY OF CRAY, INC.

■ This Cray XT3 supercomputer, upgraded with dual-core processors, now performs 54 Tflops.

If you think it's expensive to beef up your computer, try a Cray XT3™. The one at Oak Ridge National Laboratory (**www.ornl.gov**) is undergoing a million progressive upgrades that will eventually result in a one-petaflop (yes, one quadrillion calculations per second) machine. Dubbed Jaguar, it is an open scientific system, meaning that it is available to all scientific researchers and organizations, including private industry, via an annual call for proposals. Current users include Boeing, DreamWorks Animation, and General Atomics.

The upgrade involves replacing all 5212 processors with the latest AMD dual-core Opteron chips, doubling the memory to 21 TB, and adding additional cabling to double the bisection bandwidth. The machine is scheduled to hit the 250-Tflop level by late 2007 and the 1-Pflop level by 2009, but for now, users will just have to make do with 54 Tflops. The revamp is costing a reported $200 million, but it is rumored that Cray is throwing in a free extended keyboard to sweeten the deal.

PROGRAM CUTS IMAGE SPAM

Bad news continues in the war on spam, with some sources reporting that it now constitutes 40 percent of all email, plastering the average user with 2,200 come-ons per year and costing US corporations $8.9 billion annually. Worse still, the volume is expected to increase by more than 60 percent over the next year. And because spammers are increasingly sending "image spam" (which eludes traditional filters by sending pictures rather than text), it is tougher than ever to weed out the junk. But a Danish company, SPAMfighter ApS (**www.spamfighter.com**) has come up with a new type of filter that it claims can detect and remove image spam.

It is a community-based filter, meaning that SPAMfighter users (numbering about 1.7 million as of this writing) can report image spam from their email application, thus casting a vote against a particular piece of junk. The software also analyzes the graphics by combining small images into one large one to help detect similarities in the content. Unfortunately, it presently works only with Windows XP, 2000, 98, or ME and Outlook or Outlook Express. But if you use these, you can download a 30-day trial of the Pro version for free. After it expires, you can pay $29 to keep the full version operating or drop back to the standard version for free.

WEBSITE OFFERS A SOCIAL LIFE

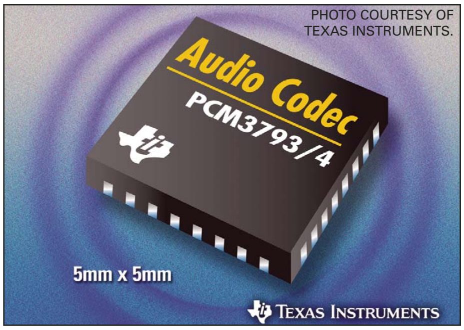
If you have been staring at the screen too much and getting out too little, a visit to **upcoming.org** might be beneficial. Brought to you by the folks at Yahoo!, it is basically an online social events listing that knows what neighborhood you live in and informs you of what's going on in the area. For example, without this site, I might never have known that there is an impending exhibition of sword handles from Indonesia at the St. Petersburg Museum of Fine Arts.

The site also allows you to add events to the calendar, so if you want some free publicity for the bake sale, all you have to do is sign up and log in. A four-minute video about the service can be accessed at **upcoming.org/media/screen/quickstart**.

CIRCUITS AND DEVICES

NEW CODECS OFFER IMPROVED PERFORMANCE

PHOTO COURTESY OF TEXAS INSTRUMENTS.

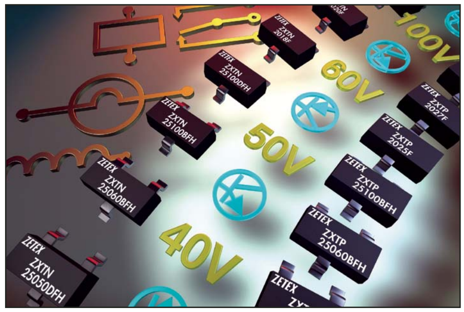


■ The PCM379x codecs are aimed at portable consumer audio devices.

Texas Instruments (**www.ti.com**) has introduced two stereo audio codecs for battery-operated devices such as digital cameras and media players. Designed to extend battery life by lowering power consumption, the PCM3793 and PCM3794 devices offer a signal-to-noise ratio of 93 dB, a notch filter with programmable center frequencies, tone control, and 3-D enhancement to make the speakers sound farther apart. The PCM3793 version increases power efficiency through the integration of TI's class-D amplifier, which drives 700 mW into a eight-ohm load. The PCM3794, on the other hand, has no speaker outputs, so OEMs can use an external amplifier. Both are provided in a 32-pin, 5 x 5 mm QFN package and will cost between $4 and $5 in 1,000-unit quantities.

MID-VOLTAGE TRANSISTORS INTRODUCED

Zetex Semiconductors (**www.zetex.com**) has introduced a family of mid-voltage bipolar transistors that are capable of handling a power dissipation of up to 1.25W. With the SOT23 package's 3 x 2.5 mm footprint, these



■ The Zetex mid-voltage transistor family is aimed at lamp, relay, and solenoid driving circuits.

seven NPN and six PNP devices are designed to increase circuit power density by replacing the much larger DPAK, SOT89, and SOT223 packaged parts.

Spanning the collector emitter voltage range of 40 to 100V, the ZXTN and ZXTP bipolars create high-efficiency switches for lamp, relay, and solenoid driving circuits in automotive, industrial, and telecom applications. Capable of blocking voltages up to 180V and handling a continuous collector current up to 5A, the transistors will switch loads as high as 500W.

In addition, pulsed current ratings up to 12A mean that higher-capacitance MOSFETs and IGBTs in power supply circuits can be driven at higher speeds. Available now, they are priced between $0.162 and $0.227 each in manufacturing volumes. **NV**

INDUSTRY AND THE PROFESSION

IPTV ON AN UPWARD TREND

For those of us who would like to see a lower-cost alternative to the local cable company, there is hope in the concept of Internet Protocol television (IPTV), which delivers video programming from your broadband connection to a standard TV set. According to the research and consulting firm Gartner, Inc. (**www.gartner.com**), the number of households around the world that subscribe to IPTV services will reach 48.8 million by 2010, with North American subscribers doubling every year. According to a Gartner report, growth will be somewhat retarded because service providers will compete with cable and satellite companies primarily on a price basis, which makes them wary of the revenue potential, and because they are still trying to figure out how to match the competition in functionality and content choice. However, as the cash flow from voice services continues to decline, carriers will increasingly look to IPTV to make up the difference. With a little luck, that will translate into something good for consumers.

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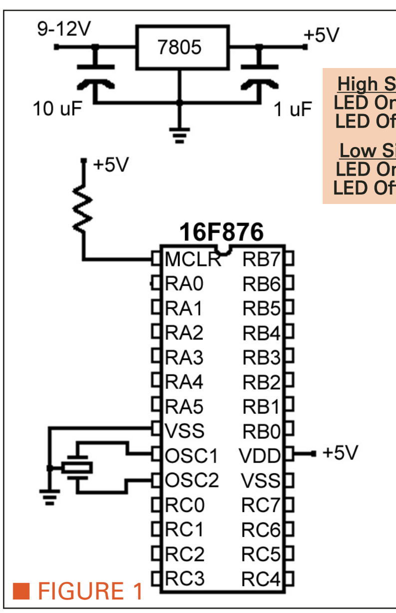
■ BY CHUCK HELLEBUYCK

PIC HARDWARE INTERFACE

PROGRAMMING MICROCHIP'S PICS IS A LOT OF FUN, especially if you have a nice development board with all the connections pre-wired for you. My BasicBoard, built around the 40 pin Atom chip (16F877A with Atom bootloader installed), was designed just for that purpose. A beginner could get a lot of programming in before they ever have to build custom circuitry around their PIC micro-controller. What I've found from reader feedback is a lot of people are looking for a little guidance with those custom circuits. I'm more than willing to help.

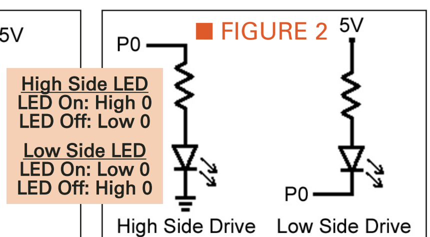
Let's start with the basics. A PIC needs four main connections to run: Vdd (typically 5V), ground (Vss), MCLR pull-up resistor, and an oscillator. Some PICs offer an internal oscillator option and also an internal MCLR pull-up. That reduces the connections down to Vdd and ground (Vss). I'll let you explore the data sheets for that information and stick with the four connections as shown in Figure 1. I also throw in a standard 7805 regulator to produce the five-volt power. There are loads of other five-volt regulators you could choose, but the 7805 is so robust and cheap, I still like to use it.



■ FIGURE 1

LEDS

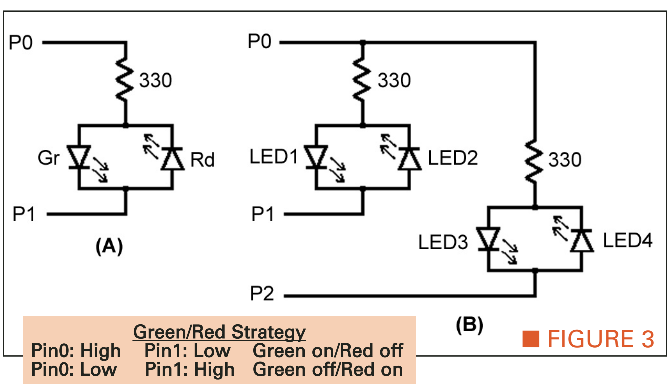
These days, just about every project will have at least one LED connected to an I/O pin even if it's just to indicate that the PIC is running. As simple as that sounds, there are several ways to do it. Most PIC I/O pins can supply 25 ma or sink 25 ma, so driving an LED directly is pretty easy, as shown in Figure 2. I show both a high side drive and a low side drive. The high side supplies the power to the anode through a current limiting resistor and the low side supplies the cathode ground path. Both work equally well, they just take a little different code setup as shown.



■ FIGURE 2

Another LED option is to drive two LEDs from the same two I/O pins, as shown in Figure 3A. This is a great way to show an error mode. Have one LED the color red and the other LED green. When the pin 0 in high and pin 1 is low, the green LED is lit possibly to indicate everything is running properly. When something goes wrong — such as a sensor signal lost or some other known problem — then the I/O is reversed making pin 0 low and pin 1 high. This will light the red LED and turn off the green LED.

Now take this concept a little further and drive four LEDs from three I/O pins as shown in Figure 3B. This saves I/O pins and allows you to control each LED individually. Table 1 shows how to light the various LEDs.



■ FIGURE 3

SWITCHES

Switches are another area that initially seems straightforward, but get more complicated when you look at the hardware options. Switches can be high side or low side activation that either pulls an I/O pin high or low, but there is a little glitch to switches called switch bounce. Inside a momentary push button switch, or most switches for that matter, is a spring steel conductor that completes the connection between two pins. When you press the switch, the spring metal contact

actually makes contact and then springs back enough to break contact and then makes contact again. It will continue to do this until it settles down, just like the spring at the wheel of a car that has worn out shock absorbers. This is a problem for a microcontroller and is known as switch bounce.

PIC software will respond so fast to switch bounce it can look like several presses of the switch instead of just one. Therefore, we need to add the electrical equivalent of a shock absorber or a capacitor to "de-bounce" the switch. There are also software techniques to handle this, but I've found that adding a small cap across the momentary switch so successful, I rarely waste code for switch de-bounce anymore. Figure 4 shows a high side switch and a low side switch with the de-bounce cap in place.

To read the switch, I would just use an If-Then-Else statement like the Basic Atom example for a low side switch below:

```
LED var P1        'High side drive LED connected to pin P1

Loop
      If IN0 = 0 then
      Low LED   'Switch open keep LED off
      Else
      High LED  'Switch was pressed, LED on
      Endif
Goto Loop
```

There are times when you need to read several switches but only have a few I/O left. This can easily be handled with a larger PIC, but it can also be handled with an Analog-to-Digital (A/D) port. The schematic in Figure 5 shows three switches that all affect the voltage at the A/D pin. When no switches are pressed, the port has five volts present. The A/D reading at this point will be 255 if it's configured as an eight-bit A/D; 1024 if it's 10-bit. When switch S1 is pressed, the voltage drops 10/11ths of the five-volt level which will be a reading of 231 for eight-bit and 931 for 10-bit. S2 will result in half the five volts with readings of 127 for eight-bit and 512 for 10 bit. Finally, S3 works out to 1/11th of the five volts and 23 for eight-bit, 93 for 10-bit.

If I use the Basic Atom to read the switches, then the following series of If-Then commands should do the trick. It checks each switch in order and it bases the decision on a value less than the expected A/D value to allow for tolerance in the resistance. You would have to play with the values of the If-Then statements to make it work in your setup.

```
Sensor con   AX1
Value var word

Loop:
    ADCIN  Sensor,3,ad_ron, value
    If value is > 1000 then loop
    If value is > 920 then S1
    If value is > 500 then S2
    If value is > 80 then S3
    If value is < 10 the short
Goto loop

S1
'…..add code for S1 switch action
Goto loop

S2
'…..add code for S2 switch action
Goto loop

S3
'….add code for S3 switch action
Goto loop
```

As you can see, by reading the port and doing a little comparison in your code, you can easily determine which switch is pressed. The problem with this setup is you can't really tell if two switches are pressed. The S3 switch will pull down the circuit to the point that you can't really tell if the others were pressed.

HIGH CURRENT I/O

There will be times when you want to control higher current hardware from the PIC. There are so many ways to do it with FET driver chips and solid-state relays and more. One of my favorite, though, is the simple bipolar NPN transistor. Because the PIC can supply plenty of base current, driving a transistor is quite easy. Figure 6

P0	P1	P2	LED1	LED2	LED3	LED4
0	0	0	Off	Off	Off	Off
1	0	1	On	Off	Off	Off
0	1	0	Off	On	Off	Off
1	1	0	Off	Off	On	Off
0	0	1	Off	Off	Off	On
1	0	0	On	Off	On	Off
0	1	1	Off	On	Off	On
1	1	1	Off	Off	Off	Off

TABLE 1

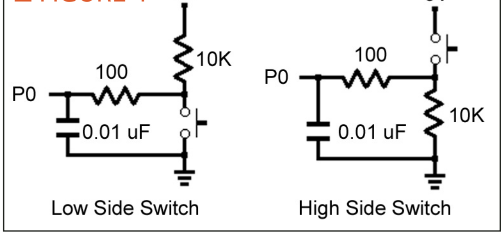


FIGURE 4

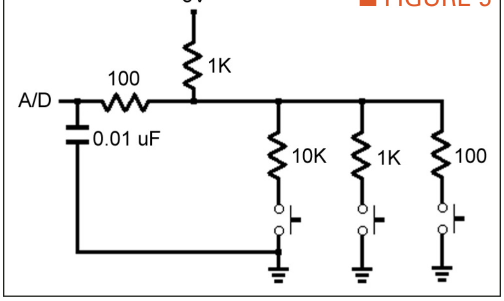


FIGURE 5

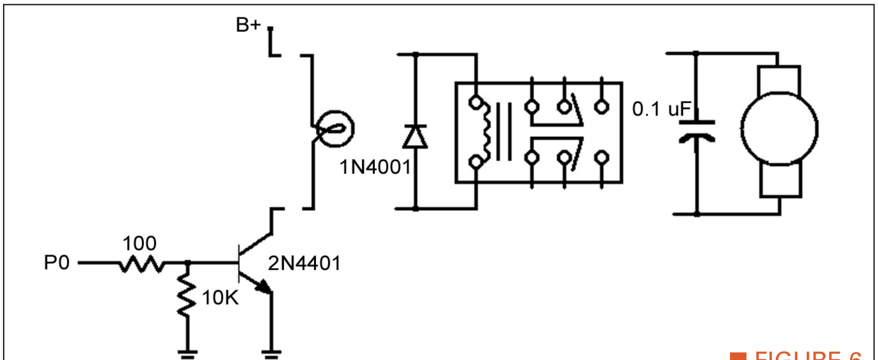
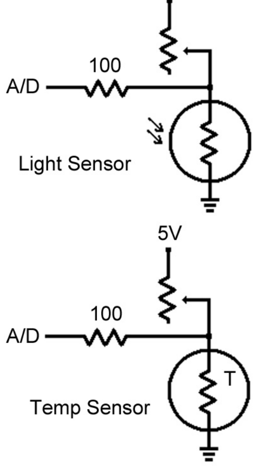


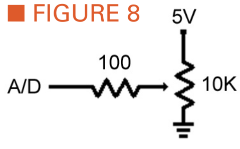
FIGURE 6

shows a standard NPN interface. The loads shown in the picture can be numerous objects. An incandescent light bulb, a relay, a motor, a high current bank of LEDs, a buzzer, a solenoid, just about anything that needs to be switched on or off and draws less than 300 ma can use this circuit. Bipolar transistors are pretty tough so as long as you don't exceed the current limits or heat limits, you should be fine.

■ FIGURE 7



■ FIGURE 8



Notice in Figure 6 that the relay has a diode across it. This is to bleed off the excess current stored in these inductive devices when the transistor is switched off. Without that diode, the transistor can see a large voltage spike at the collector which could damage the transistor. That large spike can also cause electro-magnetic interference to the PIC if it's big enough.

Also notice that the motor has a capacitor across it. This helps to knock down the continuous electrical noise generated by a spinning DC motor. That noise has reset the PIC multiple times in cases where I used a large motor without a cap. Took me a while to figure out why my code wasn't working only to later discover I had left off the cap.

Driving the transistor isn't any different than driving a high side LED. A HIGH command will turn the transistor on and a LOW command will turn it off.

SENSORS

To read a resistive sensor, I go back to the setup I used to read multiple switches and use an A/D port. A light-dependent resistor (sometimes known as a CDS cell) can be used in this method, as shown in Figure 7. I also show the same circuit with a thermistor in place of the CDS cell. Basically, any resistive style sensor can use this method. A series resistance of 100 ohms is always good to include just in case the sensor connections are shorted to power somehow. The PIC's internal protection will prevent it from being damaged, but why not protect the port from that high current with a cheap 100 ohm resistor?

Neither of these will be linear, so you have to use some kind of look-up table in your code to react to the reading. If it was linear like a straight line response, then just using an equation would be simple. This is where compilers with floating point math are handy. You can use a complex equation rather than a lookup table to process the signal. The Atom module software, despite being a free download, offers floating point. This is one of the reasons I like using this software for some of my development.

The code for reading one of these sensors is shown using the Basic Atom code again, though this time I use the LOOKDOWN command instead of a series of If-Then's.

```
Value var Byte
LED var Byte

Loop
ADIN ……
Lookdown value, >,[10,50,100,200,400,600,800,1000], LED
High LED
Goto Loop
```

The program reads the A/D value and stores it in variable "value." Then the program uses the LOOKDOWN command to convert it to a single digit. The "greater than" sign does a significant function in that it makes the LOOKDOWN command search the list for the last value that is less than the contents of "value" and records its position in variable LED.

For example, if the A/D reading of the sensor came back with 460, then the value of LED would be 4 because it starts counting at 10 and assigns it the location 0; 50 is 1, 100 is 2, and so on. Since 460 is greater than 400 but less than 600, it assigns LED the value 4. The HIGH command will then drive the P4 pin of the Atom PIC chip (PortB bit4 in PIC terms) and an LED would light if it was connected in a high side drive arrangement. If you want to do this same function in PICBasic Pro, then you need to use the LOOKDOWN2 command.

POTENTIOMETER

Taking the resistive sensor a step further, reading a potentiometer with an A/D port is quite easy. Feeding one side of the pot to five volts and the other to ground lets you connect the center wiper to the A/D port through a 100 ohm protection resistor, as seen in Figure 8. Now you can read any position of the pot by monitoring the A/D value. This makes for great position feedback in a robot or any control situation that will allow you to tie the output to the shaft of a potentiometer. A slider potentiometer will work the same way with this setup. If you are trying to control a position table, you can use a long slider pot to give position feedback to the PIC so it can drive the position table motor to the correct spot.

CONCLUSION

It's pretty clear that I've only touched the surface of PIC interface circuitry. In previous articles, I covered driving LCD modules, LED displays, and RS232 level shifter circuits. With this set of circuits, you should be able to build 90% of your first projects and then do an Internet search for anything unique. Once you have a list of these circuits, it makes it easy to go back and reference them rather than re-invent the wheel every time. I built my breadboard modules based on some of these circuits. Once I used them more than 10 times, I would lay out a circuit board and turn it into a new breadboard module. It makes prototyping so much faster. You can do the same on your workbench, building in one circuit at a time. Pretty soon you'll have a whole collection of PIC interface modules to build from.

Keep those emails coming to chuck@elproducts.com. I'm getting great ideas from readers and it lets me know I'm keeping people interested. If you are really experienced and find these columns boring, I'm sorry, but I really want to help more people get started with PICs. The number of emails keeps growing, so it seems I'm helping more and more every month. **NV**

ramsey

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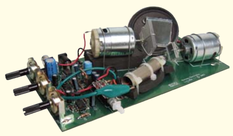

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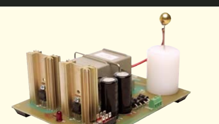

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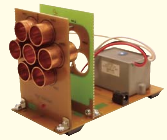

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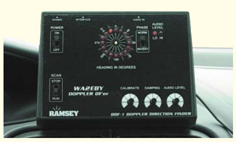

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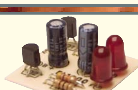

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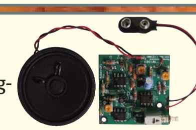

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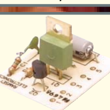

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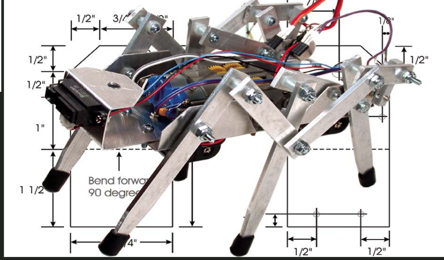


■ BY PHIL DAVIS and KEN TAIT

THE SAGA OF THE SILVER BOMBER — PART 2

WE APOLOGIZE FOR THE DELAY in getting Part 2 out to you — it couldn't be helped. As mentioned last month (in the Balancing Bot article), due to the RoHS (Restriction of Hazardous Substance) Directive, we had a tough time procuring parts and the needed PC boards, so this delayed being able to actually build and test a controller.

In Part 1 of this article (two months ago), we explored how finding some surplus Silver Bombers led to the development of a controller for the motors they contained. We explained what would be required to run various motors of this size and came up with a practical design.

Anyway, after much prodding and re-selecting of parts, Ken was finally was able to assemble a complete unit. Photo 1 shows what it looks like with a temporary heatsink installed, which we reshaped on Jerry's mill one night to facilitate the testing process. The final version will most likely have a different heatsink arrangement.

SIGNAL REQUIREMENTS

Basically, this controller is just a high powered H-bridge, with no onboard CPU or smarts. Consequently, we have to be able to drive it in some fashion. The controller requires only four basic signals to make it run. These are:

- An enable signal to turn the whole system on.
- A direction signal for forward and reverse control.
- A fan enable signal, although this could be set to run constantly.
- A PWM signal to control the speed. This signal line, in conjunction with the enable signal, also initiates a braking action when the PWM signal is removed.

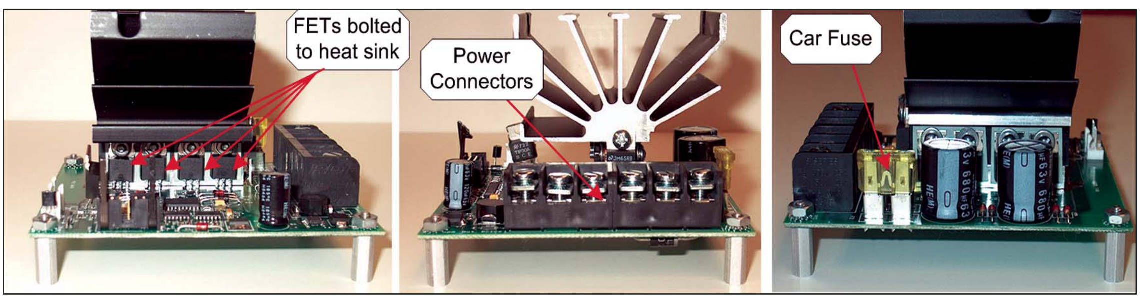
Since all these signals go through opto-isolators, they require an active low drive signal, which can easily be provided by NPN transistors or a microcontroller port pin.

Let me describe the function of each signal in more detail. The enable signal effectively kills the whole controller by telling the HIP4081A driver to turn off all of the outputs. This effectively 'floats' the FETs and no voltage is applied to the motor.

The direction signal (as the name implies) causes the driver chip logic to enable the appropriate FET set to apply the correct polarity to the motor. Note that there is really no such thing as forward or reverse, except in how you set up the motor direction in your application.

This signal will cause current reversal in a very short amount of time, not necessarily a good thing when powering large motors. Instantaneous current reversal causes large current spikes in the system and stresses on the parts. Energy has to go somewhere. For all practical purposes, you can't reverse a motor's direction that fast anyway. It takes a finite amount of time to arrest the inertia and for the magnetic field to collapse before an actual, physical reversal can occur. It's important to build some delay in the driver software to accommodate this.

The fan enable signal turns the fan on or off. If using



■ PHOTO 1. A 50 amp motor controller.

a brushed motor type of fan, it's possible to apply a PWM signal here and control the fan speed.

The PWM signal is one of the key elements. I have seen much debate in the forums over what the correct frequency is for various types of motors. This question has also puzzled me for some time. For smaller motors, I have used frequencies in the 200 Hz to 15 kHz range in the past and haven't really found much difference in performance. I found some equations that are supposed to define the ultimate PWM frequency for a particular motor. Plugging in the numbers produced a frequency for the Silver Bomber motors in the MHz range. While this sounds reasonable, in many respects, this is totally impractical.

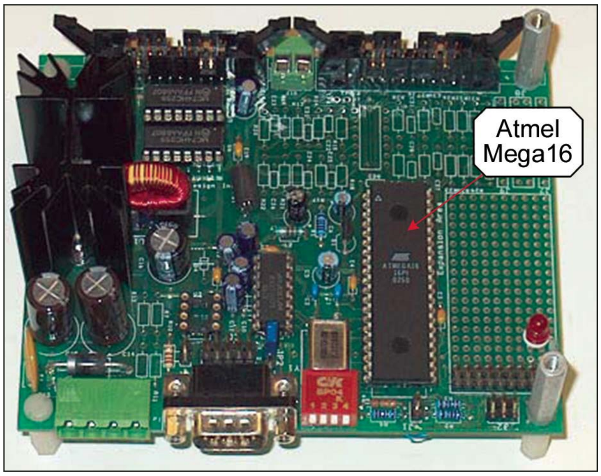
First, the FET switching losses at these frequencies produce a large amount of excessive heat, energy that isn't going into the motor. Second, these frequencies also produce funny eddy currents in the actual PC board and certain components, not to mention the RF issues. I bounced this question off my friends that design motor controls for a living.

Their response was to use the highest frequency you can get away with. So, at frequencies under 20 kHz, the motor windings might 'sing' and produce some audible noise. This may not be objectionable, after all, this is going in a large robot and it might be a good idea to hear it coming. Let's see what we can do to generate the signals.

THE SIGNAL GENERATOR

I have a small Atmel-based 16 channel servo controller I made some time ago and thought this might be a good choice to use as a CPU board to test the motor controller with. This board has a 40-pin DIP socket and can take a number of different types of Atmel CPUs. I plugged in an ATMEGA16 CPU and wrote some code using the CodeVision C compiler — one of my favorites because I already had a lot of working code modules and could save some time (see Photo 2).

The CPU board has a 7.3278 MHz crystal, used to generate accurate baud rates, so this was the determining factor in what PWM base frequencies I could generate. I configured Timer1, a 16 bit timer as a phase correct 10 bit (1,024 steps) PWM generator. I set the pre-scaler to 1 so the counter ran at the CPU clock frequency. For a phase correct PWM, the frequency follows this equation:



■ PHOTO 2. CPU board used to test the motor controller.

PwmF = CpuClk / 2 * Prescale value * Top value

This works out to:

7327800 / 2 * 1 * 1024 = 3,578 Hz

Not quite what I wanted, but we'll try it. If I lowered the PWM resolution to eight bits, this would raise the frequency to 14,312 Hz, closer to the mark. It is possible to generate higher frequencies, but this involves more timer manipulation.

I reconfigured four of the servo output bits to use in driving the other required signals. Referencing my previous comments on the necessary control signals and delays required, I added these functions to the software.

Now that I had a platform to generate the required signals, how could I control the motor operation dynamically to test various aspects of the controller? I could have added a potentiometer to the signal generator, plus a few switches to have some user control, but that's too easy. Besides, I can ultimately have more control if I use a PC-based application which drives the CPU board/signal generator.

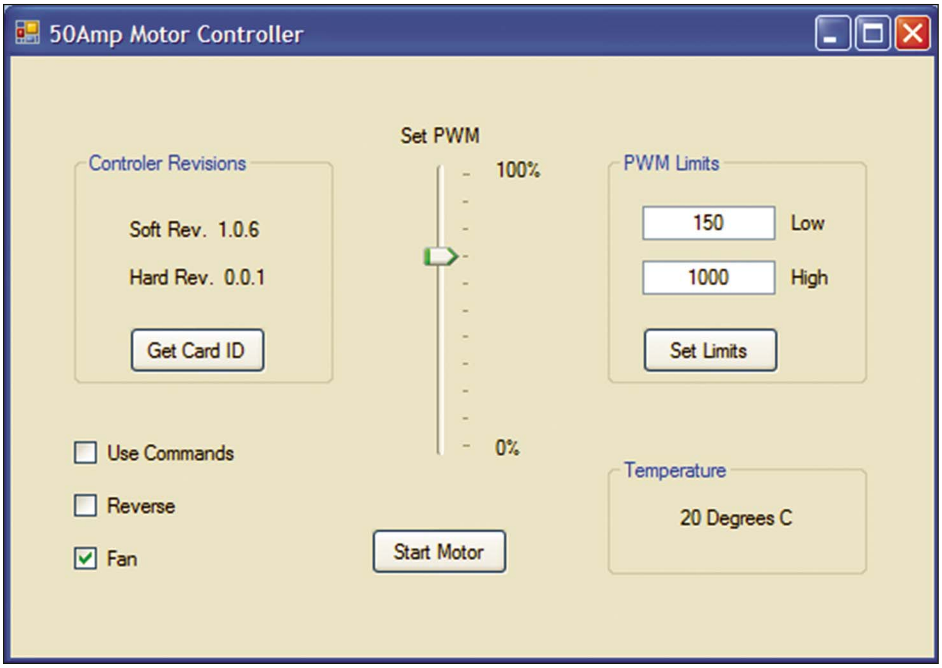
CONTROL DIALOG

I have a Windows hosted application I use for various test platforms and other personal projects around the shop. It features a fairly robust control protocol usable over any type of media. I configured a communication module for the Atmel CPU, wrote a simple motor control command set, and got this running. You can see the control dialog in Photo 3.

The dialog implements a mechanism to determine if a communications link has been established. If so, the software and hardware revision levels are reported. A simple slider controls the PWM value, and checkboxes control forward/reverse and fan control.

I added the ability to set an upper and lower PWM limit because it is useful to sometimes restrict the maximum motor speed with an upper limit. The lower limit sets the minimum value that actually causes the motor to rotate with its associate load attached. These values can be used with smarter control software to overcome the static load present at a dead stop. For instance, if your RoboMagellan bot is navigating the course, this load can vary quite a bit, depending upon the slope of the terrain the robot platform is sitting on. Probably the best way to manage motor torque and RPM is by using an encoder on the motor shaft.

The Start Motor/Stop Motor button controls the sequencing of events to initiate action. I should note here that the reverse checkbox and the start/stop button are logically tied together. Since we don't want to suddenly hit reverse when going full out (for reasons mentioned earlier), checking the reverse box will first initiate a stop, then a reverse, then a start with small delays in between, assuming the motor was running to begin with. The



■ PHOTO 3. Motor control dialog.

'Use Commands' checkbox is for future capability to queue up multiple commands so a motor control profile can be built and stored, for example, an acceleration or deceleration profile.

The temperature indicator samples the heatsink temperature on a periodic basis. Smarter software can use this to set limits and to prevent self-destruction of an overtaxed controller. The temperature can also control the fan operation to lower the power drain when the system is idle.

BOARD CHECKOUT AND TESTING

As I mentioned in Part I, dealing with large currents on small PC boards can be dangerous ... I reminded myself of that fact when I first powered up the board, so I brought the controller to life in stages.

First, I populated the DC/DC and power supply components and tested for correct operation. When I first powered it up, a capacitor blew, just missing my nose peering into the works!! This was due to my rushing the assembly and putting it into the board with reversed polarity. Luckily, there was no shrapnel.

Next, I added the opto-isolators and related logic to be sure the correct signals were produced. I powered it up again and measured signals with an oscilloscope.

This was followed by the driver section and protection components buildup, everything except the FETs. I scoped the driver outputs again to be sure nothing was disturbed.

Lastly, the FETs were added on the heatsink before being soldered into the board. Particular care must be taken in this step. Each mounting tab is electrically connected to the center pin of the FET. They are NOT electrically connected in the design. This means that each FET must be isolated from the heatsink. This is done with an insulated phenolic washer and a thermally-conductive pad instead of heatsink grease. This is a lot less messy and provides the needed isolation. Each FET was tested with an ohmmeter to be sure there were no shorts.

The board passed all of the above tests, so it was now time to try some motors. I connected two 12-volt batteries in series for 24 volts and connected those to the power inputs of the motor controller. I connected the Silver Bomber motor to the power outputs of the controller, and finally connected the CPU test board to the motor controller. Photo 4 shows the finished setup and you can see the serial connection going to my PC on the left.

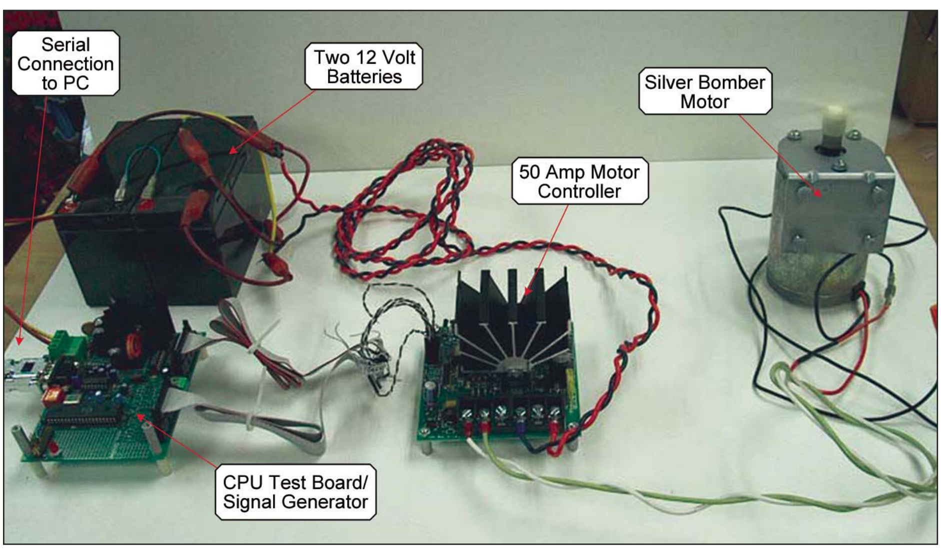
DID IT RUN?

You bet it ran. I had great control over what we estimated to be a 30-35 amp motor, from stop to moving slowly, all the way up to full speed. In Photo 4, you can see the propeller I had on the motor shaft whizzing

RESOURCES

■ http://en.wikipedia.org/wiki/RoHS
For some information on the RoHs initiative.

■ http://hpinfotech.ro/html/cvarv.ht
For information on the CodeVision compiler.



■ PHOTO 4. Test setup configuration.

around. The controller (as tested) is designed to easily drive a 50 amp motor. By adding an additional four FETs, we can crank that up to over 100 amps.

SUMMARY

Well, I've taken you through some of the steps in bringing a motor controller to life and some of the software issues involved in making it go. For space and time reasons, I've left out a lot of details. Other roboteers have told me they are not always concerned with lots of details, but more interested in the overall process of bringing a design to life. It's in that vein that I wrote this article.

I hope you have seen that it's not easy to successfully and safely do this when you get above a certain power level. It requires a lot more attention to details.

I like to stress that if you try and build something like this, make sure you apply the proper precautions and safety factors. I can't say this enough times. And remember, and no rings or jewelry when working on power equipment — gold melts quite easily. The unexpected happens and with a 24V supply at 50 amps, that's 1,200 watts that has to go somewhere ...

Time allowing, we will try and do a follow-up article with some additional real life testing: stall tests, temperature tests, and perhaps a destruct test. We would also like to try the controller with four additional FETs. **NV**

Q&A

WHAT'S UP:

The days are short and the nights are long — a perfect time to heat up the ol' soldering iron.

- ✔ **Digital pot light fader.**
- ✔ **DVM high-voltage probe.**
- ✔ **Golf cart gas gauge.**
- ✔ **$10 audio mixer.**

■ WITH TJ BYERS

In this column, I answer questions about all aspects of electronics, including computer hardware, software, circuits, electronic theory, troubleshooting, and anything else of interest to the hobbyist.

Feel free to participate with your questions, comments, or suggestions.

You can reach me at: **TJBYERS@aol.com**

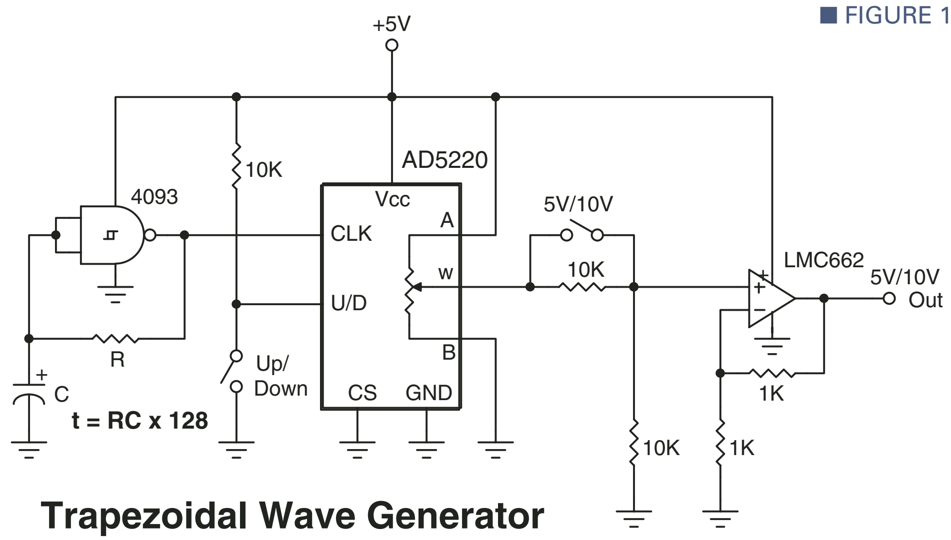
TRAPEZOIDAL LIGHT FADER

Q I am looking for a ramp generator, sort of. The ideal circuit would have a button which, when pushed would ramp up the output voltage, then the circuit would sit at a high output level until a second button was pushed which would ramp down the output voltage and then the circuit would sit at a low level until the first button was pressed again. I would really love it if the time of the ramp was variable between 0.5 and 15 seconds. And, finally, the output voltage should be 0 volts at low level and 10 volts at high level. The output current would not have to be very much, 100 mA max. The circuit would be used with an old analog theater dimmer pack. To make it even more versatile, if the output voltage high and low points could be programmed to 0-12V or 0-5V, then the circuit could be used in a variety of audio circuits, as well.

— Tyler Patrick

A What you want is a trapezoidal waveform generator. This can be done using a digital pot (Figure 1). The first gate — a 4093 astable oscillator — clocks pulses into a 128-step digital potentiometer. Two SPST (single-pole, single-throw) switches determine the direction of counting, up or down, and the output voltage, +5 volts or +10 volts. Since you have three unused 4093 gates, they can be used to drive LEDs to indicate the direction of the waveform, output voltage range, and other functions. The power supply is regulated to five volts, giving the output a range of zero to five volts; the ramp-up and ramp-down time is determined by the equation t = RC x 128. The op-amp increases the five-volt wiper voltage to 10 volts at about 25 mA, which should be enough for most applications.

■ FIGURE 1



Trapezoidal Wave Generator

But you said you need 100 mA of drive. This is easily done by paralleling two or more op-amps to increase the output current. When paralleling op-amps, though, you have to be careful that they don't feed back on each other and create unstability or overheating. The standard solution is to use small isolation resistors feeding a common line, as shown in Figure 2. There is no limit to the number of op-amps you can add to the right. However, it is better if they are all the same number — or at least the same type. Mixing parallel op-amp types is just asking for problems.

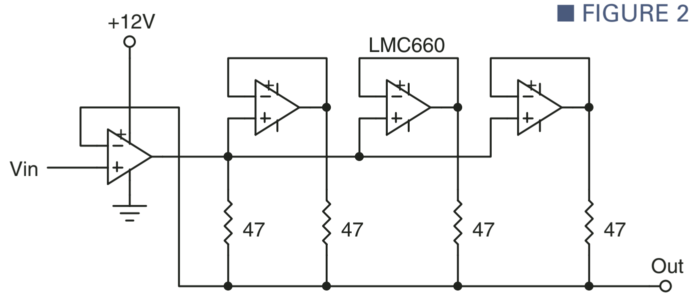
TELECOIL DEFINED

Q I got some new hearing aids that have three modes — including something called Telecoil. The manual says it is for answering the telephone. But it also said it can be used in places that have an "induction loop" system, like in churches, theaters, etc. I was wondering if it is possible to make and install an induction loop in a house, like the TV room, for radios and other devices?

— Richard Ball
Skagit Valley, WA

A The Telecoil was introduced way back in the 1940s to assist persons with hearing difficulties. The design is based on the concept of magnetic induction — the same forces used in transformers. And like a transformer, the Telecoil has a primary and a secondary winding. Originally, the earpiece in the telephone headset served as the primary of the transformer and a small iron-core coil connected to a hearing aid was the receiver. This way, the disabled person could converse on the phone without ever hearing the audio sound. The hearing aid converted the electromagnetic waves into audio via the Telecoil. Unfortunately, modern phones (with a few exceptions) no longer emit electromagnetic waves strong enough for Telecoil operation.

Today, Telecoil is mostly used for area reception — inside a church, for example. For area use, the primary winding consists of a thin wire or coil placed around the perimeter of the room or under the rug (depending on the area of interest). Figure 3 shows how to make a Telecoil loop that goes around the baseboard of an 8′-by-10′ room — as in a TV room — using plain old four-wire phone cable. The wires are spliced together near the amplifier using the color code indicated. This forms a four-turn coil with an inductance of about 384 µH. At 1 kHz, this translates to an impedance of 2.4 ohms. The loop connects to the four-ohm output of a 10W audio power amplifier with a volume control. You need this much power and control over the signal emitted by the primary coil because you will find drop-out spots as your Telecoil hearing aid moves about the room, and you need the volume control to prevent overdriving the loop that leads to distortion. You can also make Telecoil loops that serve just a Lazy-Boy recliner, a bed, or even under the seat of a car. Just make sure the coil's impedance more-or-less matches the output impedance of the audio amp. Use this calculator (**www.captain.at/electronics/coils/**) to determine the inductance of the coil and this calculator (**www.electronics2000.co.uk/calc/calcreac.htm**) to find the impedance.



Voltage-Follower Output Current Multiplier

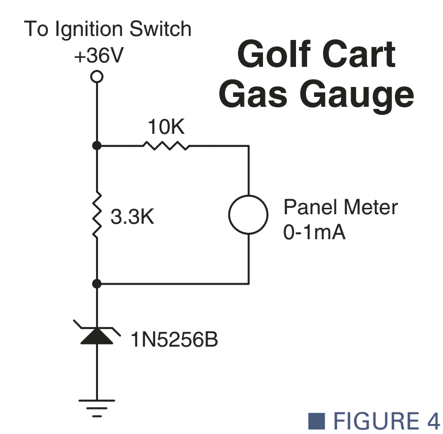
■ FIGURE 2

GOLF CART GAS GAUGE

Q Do you have a circuit for an electronic "gas gauge" for a 36V (6 or 12V batteries in series) golf cart?

— Ken Swanstrom

A A very simple gas gauge can be made using a zener diode, a couple of resistors, and a panel meter (Figure 4). The gauge is a 0-1 mA full-scale panel meter that you can find surplus for $12 or less; about $20 new. At full charge the meter will read 1.0, with the numbers between 0 and 1 representing the percentage of charge left. Although the gauge only draws 4 mA from the battery, it's best you attach it to the switched side of the ignition on/off switch.

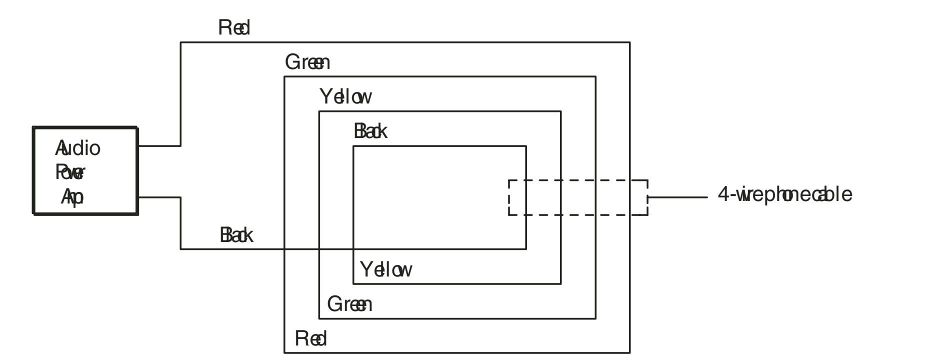


Golf Cart Gas Gauge

■ FIGURE 4

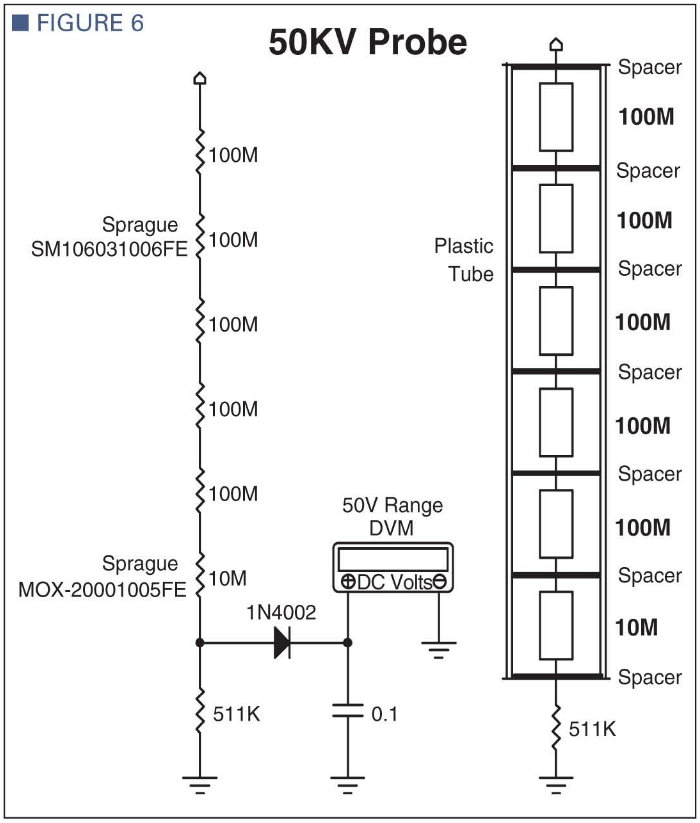
SERIAL DATA MONITOR

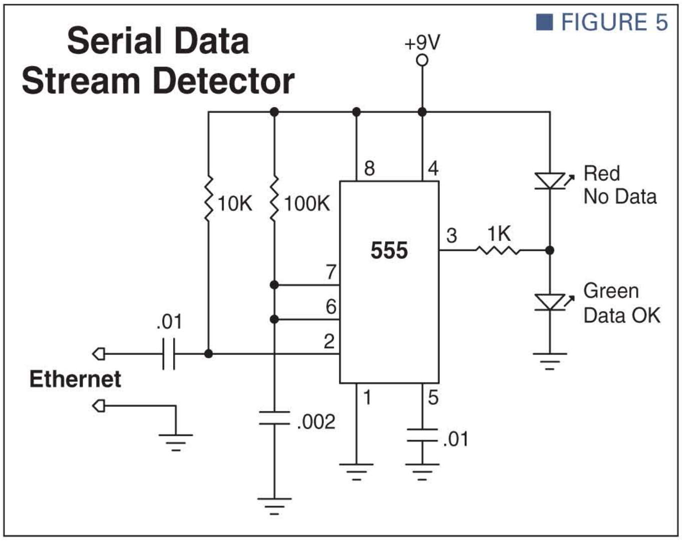
Q I am an ET (Electronic Technician) and my job requires troubleshooting a system with a serial port



Telecoil Loop

■ FIGURE 3





that sends data to a display. I need to create a monitor to tell me when there is data on the line and where there isn't. Do you have any ideas or circuit that will work?

— Andre Smalling

A I have successfully used a logic probe for this in the past. You know, one of those probes that light

MAILBAG

Dear TJ,

Here is an observation about your "Pressure Transducer Expanded Scale" circuit in the Aug. Issue. The data sheet for the MPX4115A indicates a drive capability of only 0.1 mA for a full-scale output voltage of 4.794 volts. This would imply a load resistance capability of (4.794 / .0001) = 47,940 ohms. For a differential amplifier to operate properly, the source and reference input resistances must be identical. Thus, your reference resistance divider should be about 50K. Consider using a non-inverting buffer [voltage follower] in series with the differential amp input resistors. This eliminates the problem of impedance matching (meaning you don't have to change your values) and increases the drive capability of the pressure transducer.

— Robert A. King
Electronics Circuit Designer
OmniScience
Ontario, Canada

Response: What this design really needs is an instrumentation amplifier — which aren't cheap or easy to work with. I like your solution of using buffer amps because it improves accuracy without incurring the expense of precision amps. — TJ

Dear TJ,

As to "A/C for A/V Buildin" in September '06, I believe there may be an error. Before the thermal switch opens, current will be drawn through the motor and 180 ohm resistor. Assuming an average muffin fan winding resistance of 240 ohms, the current will be about 300 mA, in which case the 180 ohm resistor would dissipate nearly 17 watts!

I believe a better solution would be to use a sensitive gate triac (e.g., Teccor L201E3; Ig = 5 mA) and change the 180Ω resistor to 24K. This resistor will dissipate about 0.6W, so a 1W resistor would be in order.

— Robert Reed

Dear TJ,

Your Q&A column in the August '06 issue of *Nuts & Volts* is the first time I've ever seen anyone suggest that running a notebook computer without the battery in place will destroy it. In fact, several sources (two linked below) maintain that notebooks that don't get out of the house much — i.e., in a desktop replacement scenario — should have their batteries removed, as charging the batteries constantly will kill them. The batteries should still be cycled once a month or so.

http://mobileoffice.about.com/od/usingyourlaptop/f/laptopbattery.htm

http://gearlog.com/blogs/digitallifetv/archive/2006/06/21/14156.aspx

— David McDermott

a green LED when the input is high, red when it's low, and yellow when there's a pulse train. The problem is that you have three connections to make. One for Vcc, one to GND, and the probe tip. That's because most logic probes use TTL or CMOS chips to display between a 1 and 0, hence the Vcc clip.

The circuit in Figure 5 requires only one connection to GND and isn't voltage sensitive. That's because it uses the falling edge of the train pulses rather than absolute voltage. A nine-volt battery powers the tester — making it totally portable — and requires just a ground clip for data stream testing. The probe will respond to data rates of 9600 baud and higher with the values shown. For slower data rates, increase the value of the .002 µF cap.

Here's how it works. The 555 is configured as a monostable multivibrator. That is, the output can be triggered high anytime the voltage on pin 2 (trigger) goes below one-third (1/3) Vcc (9V). Because pin 2 is capacitive coupled with a 10K pull-up resistor, every negative-going pulse will pull the trigger input well below this voltage. The 100K resistor and .002 µF cap determine the time the 555 output will remain high and light the green LED that will stay lit as long as the data stream continues to generate negative-going pulses. Once they cease, the red LED lights.

50 KV PROBE FOR DVM

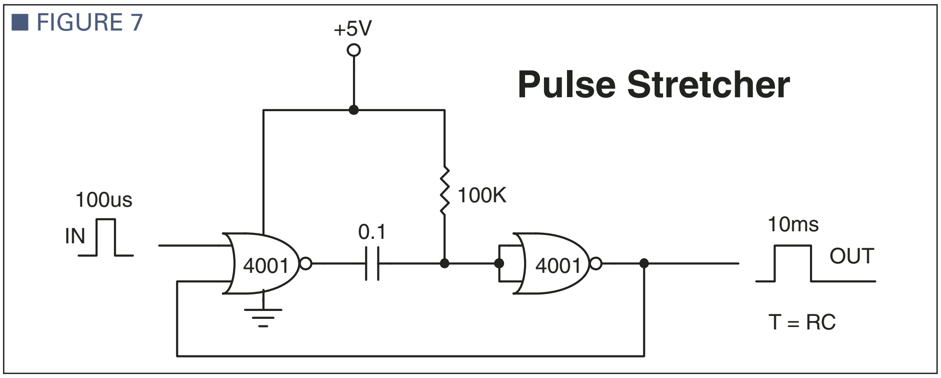
Q I'm interested in building a probe for a common DVM that could be used to measure the HV of an automotive secondary. Also, how would it be possible to calibrate such a gadget and how would the very fast peak be detected and held long enough to be read?

— Robert Dunbar

A High-voltage test probes are made by stacking several resistors together in a voltage divider, as shown in Figure 6. The resistance values are selected so as not to load down the source. With the 500 megohms shown, this gives us a test current of 98 µA — plenty of resistance for most high-voltage measurements, including spark plugs. The final divider resistor is 511K, giving the probe a full-range scale of 50 kV and an output of 50 volts (a 1,000:1 ratio). A 1N4002 diode and 0.1 µF capacitor create a peak signal detector. The resistors — available from Allied Electronics (800-433-5700; **www.alliedelec.com**) and Mouser Electronics (800-346-6873; **www.mouser.com**) — are 1%, so calibration isn't necessary.

Rather than mounting the high-value resistors on a circuit board, it's better to link them together by soldering the leads in a chain. You want to put the resistor assembly

FIGURE 7



inside a plastic (e.g., Plexiglas) tube to prevent shock. To keep the resistors centered in the tube, a plastic spacer at each solder joint is in order (see Figure 6). The end disks can be anchored in place with model kit styrene cement. A rubber bicycle hand grip over the end of the plastic tube makes a good, insulating handle.

PULSE STRETCHER

Q I got myself into a pickle. I bought a Chinese radio slave to trigger my BASIC Stamp-controlled studio slave. Problem is that the radio slave closes the switch for 100 µs, which is too short for the Stamp to detect even in a tight loop. I need to "stretch" the pulse so the Stamp can detect the radio pulse and fire the flash. Any ideas?

— Al Sanowskis
Ocala, FL

A What you need is a monostable multivibrator — also called a one-shot pulse generator. Most hobbyists would use a 555 timer, but I've been there and done that — and was not all that excited with the results. Mostly because the 555 is negative-triggered, which is the opposite of most logic. Here's what I recommend: Figure 7.

What I like about this circuit is that it's positive-edge triggered and uses cheap NOR gates. Moreover, it leaves two gates free for whatever else you want, and can be powered from any supply from 3 to 15 volts. The delay time is t = RC. **NV**

COOL WEBSITES

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Ballistic Deflection Transistor

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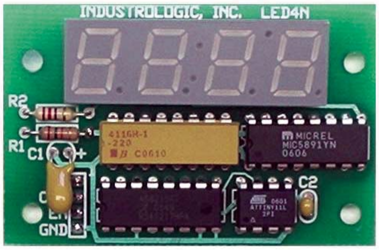
THE LED4N



Industrologic, Inc., announces the release of their LED4N — a four character LED numeric display board. It is designed to provide an easy-to-interface and easy-to-progam four character numeric LED display for nearly any microcontroller or Programmable Logic Controller (PLC).

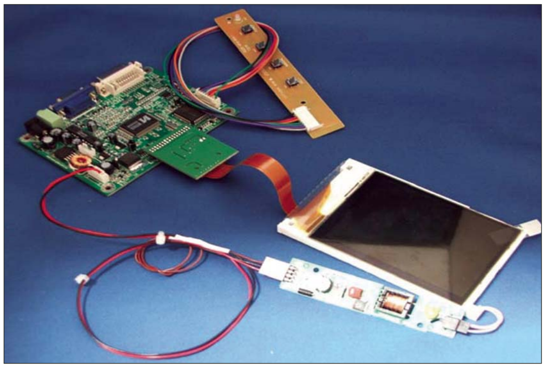
The LED4N is based on a four-digit, seven-segment "clock stick" LED display, with red 0.4 inch height numbers, a decimal point for each number, and a clock style colon. It features microcontroller controlled display segments with character sets for numeric and selected alpha characters, as well as selected punctuation.

The LED4N requires only +5 and ground power connections along with two logic level outputs from the circuit driving the display, and uses an extremely simple protocol.

The LED4N is available as a complete circuit board assembly with wiring suitable for conveniently connecting it to the screw terminal block connections of Industrologic microcontroller base boards. The board measures 2.35" x 1.5" x 0.5" and includes mounting holes for #4 screws.

For more information, contact:
Industrologic, Inc.
3201 Highgate Ln.
St. Charles, MO 63301
Tel: **636-723-4000**
Fax: **636-724-2288**
Web: **www.industrologic.com**

SMALL HI-RES DISPLAY KITS



To meet the increasing demand for small, high-resolution display kits, Solar Technologies introduces a 4" 640 x 480 TFT LCD with an analog VGA and DVI input controller.

LCDSolar's OEM-KIT-115 is built around the Toshiba LTM04C380K display and a VGA with DVI input controller, advantageous because it allows integrators to drive a very small TFT directly from their PC, thereby reducing costs and increasing flexibility, which can shorten the time to market.

OEM-KIT-115 touts the small TFT and controller card for easy drop-in or rear-mount applications. The small LCD package opens up a whole new set of options for integrators. The OEM-KIT-115 also includes auto scaling, optional touch screen, and an optional anti-reflective coating for sunlight readability. OEM-KIT-115 is ideal for embedded applications, including, cockpit flight simulation, Kiosk, hospitality, POS and POI.

"The OEM-KIT-115 product evolved as an answer to meet customer demands," says Tris Mahaffay, Sales Engineering Manager of Solar Technologies.

"Integrators needed flexibility to meet the demands of their customers' specific application, and the OEM-KIT-115 offers that flexibility at an extremely attractive price."

OEM-KIT-115 has a preliminary retail price of $379 and is flanked by a family of high-resolution display products in many sizes and configurations. Solar Technologies has a full line of LCD kits and open frames designed to suit a wide array of embedded or free-standing applications.

For more information, contact:
Solar Technologies
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This means that if the device transmits continuously at the fastest rate possible, it will still take 890 years to run out of valid packets.

Additionally, CipherLinx-based parts offer numerous features. These include a large number of data lines, multiple baud rates, individual "button level" user permissions, optional encoder PIN, encoder identity output, and a control line for external transmitters. Products employing CipherLinx components are easily configured by the manufacturer or end user and require no production programming.

The first CipherLinx-based parts are the Linx HS Series. This series consists of an encoder that will encode the status of up to eight buttons or contacts into a secure transmission. The matching decoder will decode the transmission and, following authentication, replicate the button or contact states to control external circuitry or devices. These are implemented in tiny 20-pin SSOP packages with very low power consumption, making them ideal for battery-powered applications.

The parts have been evaluated by ISE (Independent Security Evaluators), a well-known security evaluation company, who concluded an extensive report by noting the HS protocols are "well-designed" and "an excellent choice." ISE's full evaluation report and additional information may be obtained by contacting Linx Technologies.

The HS is currently in sample production and is priced at $2.54 in production volume quantities of 10,000.

For more information, contact:
Linx Technologies, Inc.
575 SE Ashley Pl.
Grants Pass, OR 97526
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Continued on Page 90

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If you haven't been to the *Nuts & Volts* forums lately, you've likely missed out on a lot of great discussions. There are over **4,000 registered users** and over **39,000 posts** covering every electronics topic imaginable.

Here are some recent topics that have been in discussion.

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- Arduino Dev Board

Current forums include:

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We've recently added a new forum called **Up For Grabs**. It's the place to **post any electronics items for sale, trade, or to give away to a good home**. It's for *private party (personal) items only*. No commercial vendors allowed. Oh yeah, and ***it's FREE***.

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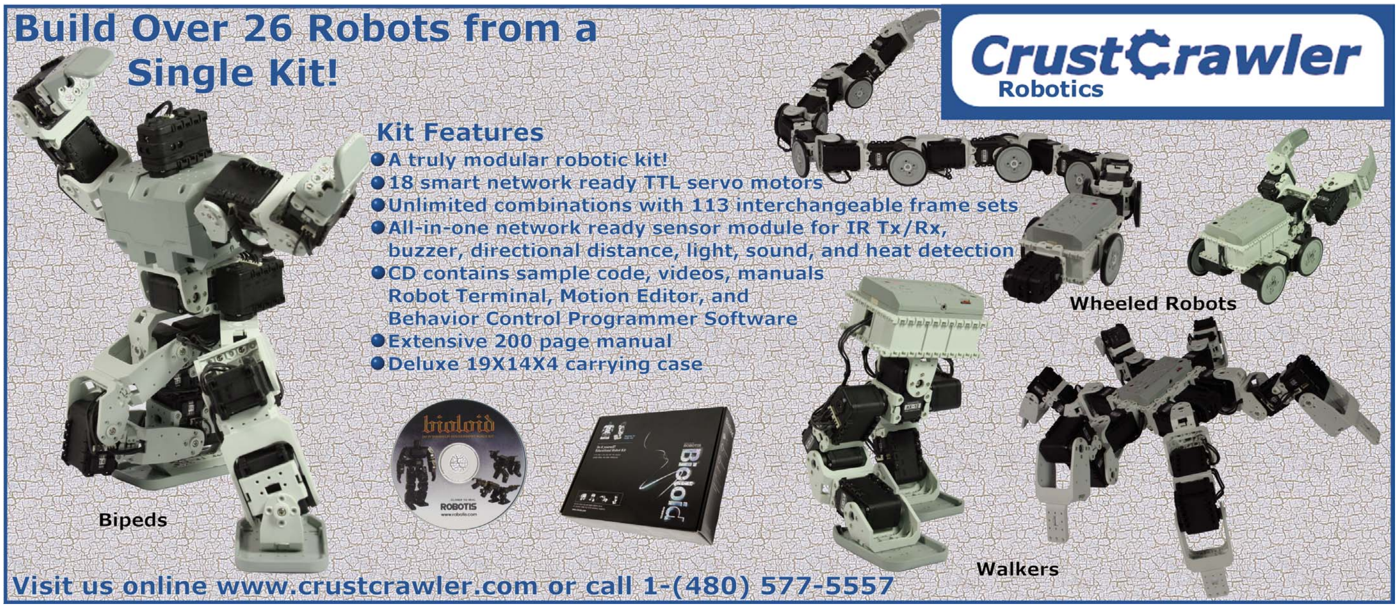
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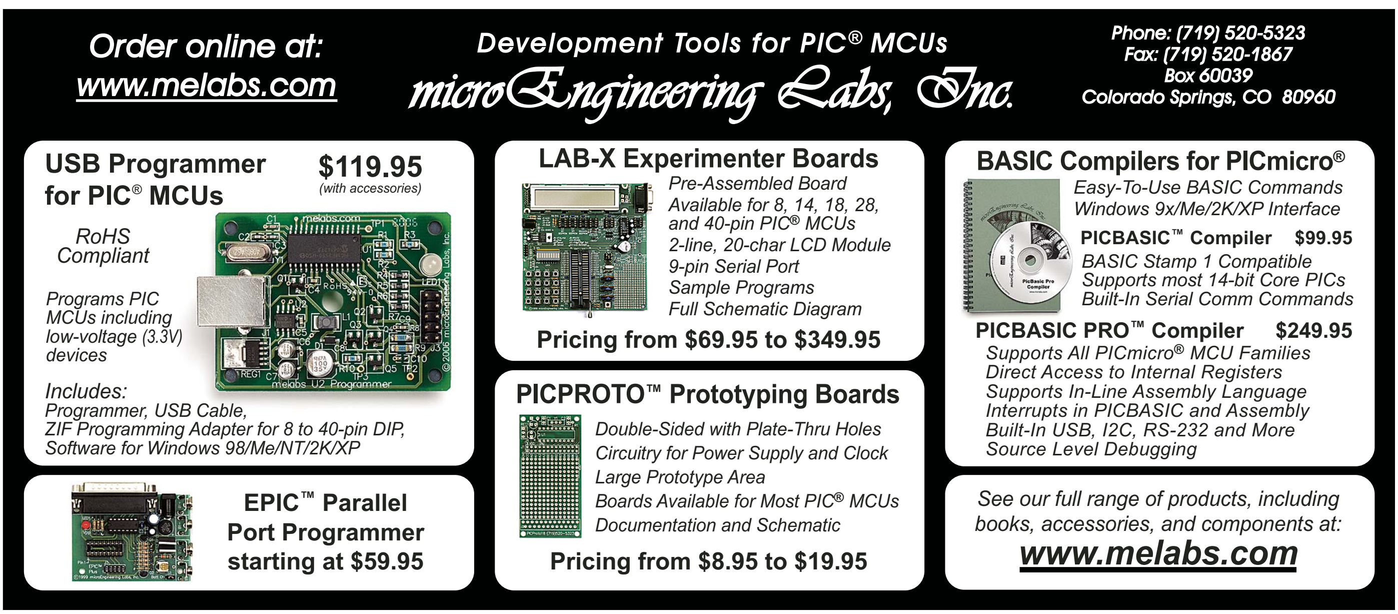
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Cleverscope software resources include:
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RESTORING THE PHILCO PT-44 ANTIQUE RADIO

The first vacuum tube radio I repaired was a gift from my great-grandfather.

It was a beautiful Sparton wooden radio from the 1930s. It had an organic look, feel, and sound that cannot be replaced by anything available today. I still remember his stern warning to be careful with that radio. "It could kill you!" Since then, I have collected many radios and have learned a great deal about their design and restoration. I also learned why my grandfather's warning was so important.

This article chronicles the restoration of a 1941 Philco model PT-44 vacuum tube radio shown in Photo 1. As I worked on this radio, I often found myself wondering who owned it. What did they listen to? Did this radio deliver the original radio broadcast of President Roosevelt's address to Congress, *"Yesterday, 7 December 1941 — a date which will live in infamy ..."*

The featured radio was purchased in a recent eBay auction for US$53. Overall, it was in decent condition. The wooden cabinet was water damaged and the laminations were parting. The radio received local stations but produced a constant 60 Hz hum. In this article, I will tell you how I performed the electrical and cosmetic restoration with emphasis placed on the electrical restoration.

■ PHOTO 1. Restoration complete for this 1941 Philco PT-44 table-top radio. It looks and plays as well as it did 65 years ago.

For this project, I assume you have a basic knowledge of electronics. If you plan on working with antique radios, you will need basic hand tools and a good soldering iron. A bare minimum of test equipment is required. You can do the majority of your radio work with a cheap voltmeter.

Safety First

An antique radio can be an electrocution waiting to happen! We are dealing with a high-voltage line powered piece of electronic equipment. In the old days, safety standards were not as stringent as they are today. In fact, most radios of the '40s and '50s left out the #1 safety device — namely, the power (isolation) transformer. *BEWARE! Occasionally, you will find a radio where the power cord is connected directly to the chassis!* Therefore, treat all radios the same way you would an exposed live power cord.

The manufacturers did take some safety measures, however. The chassis, including the volume and tuning controls, were insulated. Most

radios had a back cover to prevent users from touching the chassis. Some radios, such as the featured Philco PT-44, have circuitry that isolated the line voltage from the chassis. Unfortunately, none of these safety measures will protect you when servicing the radio.

The best safety measure is to be prepared for the worst. Obviously, unplug the radio while you are working on it. Use a voltmeter to check for voltage on the capacitors as they can store a nasty charge. Use an isolation transformer. You should have a CPR qualified family member or friend watching you. Instruct them how to kill power to the radio in an emergency. Tell them not to touch you or the radio or they could become victim number two. Finally, consider safety modifications to the radio.

Safety Modifications

Antique radios are inherently dangerous. The greatest danger comes from the chassis being electrically hot. A GFI power cord should be installed on the radio to minimize this danger. You can salvage a GFI power cord from a modern hair dryer. Recall that a GFI is designed to remove power if a ground fault is detected, i.e., you have become part of the circuit by simultaneously touching the radio's chassis and a ground.

Modern power cords are polarized in that they only plug into an outlet one way. (This can be a blessing and a curse.) Polarized plugs work well for the lethal power line directly connected to chassis-type radios. Simply connect the return (neutral) line to the chassis. For radios such as the featured Philco PT-44, things are not as simple. As previously mentioned, this radio has circuitry to isolate the line from the chassis. Unfortunately, the system is not 100% effective. The power line is capacitively coupled to the chassis. A 120 VAC signal will be felt on the chassis no matter which way the power cord is connected.

You can verify this using a small neon lamp as shown in Photo 2. If the power cord is connected one way, the lamp will always light. Connect the power cord the other way and the lamp will light when the radio is turned off. You can rewire the power switch so that it is in the opposite leg of the power line. This is a simple operation readily apparent when you have the schematic in hand — not so apparent if you are just looking at the chassis wiring. This, plus the GFI power cord, should protect you from your antique radio.

■ PHOTO 2. Beware of the live chassis as indicated by the glow of the neon lamp! Believe it or not, this is normal operation for this type of radio. This picture shows an unmodified Philco "Hippo" radio chassis model 48-460.

A fuse should be installed in the radio on the hot side of the power line at the point of entry. This will minimize fire danger should the radio develop a fault. Recall that your house's circuit breakers are designed to protect the house's wiring, not the electrical devices that happen to be plugged into the wall. Your radio would have to draw over 20 amps to trip the circuit breaker. It is unlikely that this would happen. Instead, the offending component(s) would heat up, explode, or catch on fire.

To Modify or Not to Modify

It depends on your experience level and on what type of radio you have. Vacuum tube radios will never be made again. Every time a set is modified or restored, a piece of history is potentially lost. Also, some radios are worth a great deal of money. I've seen radios that sell for thousands of dollars on on-line auctions. Your skill in restoring a radio will have an impact on the ultimate historical and monetary value of the radio.

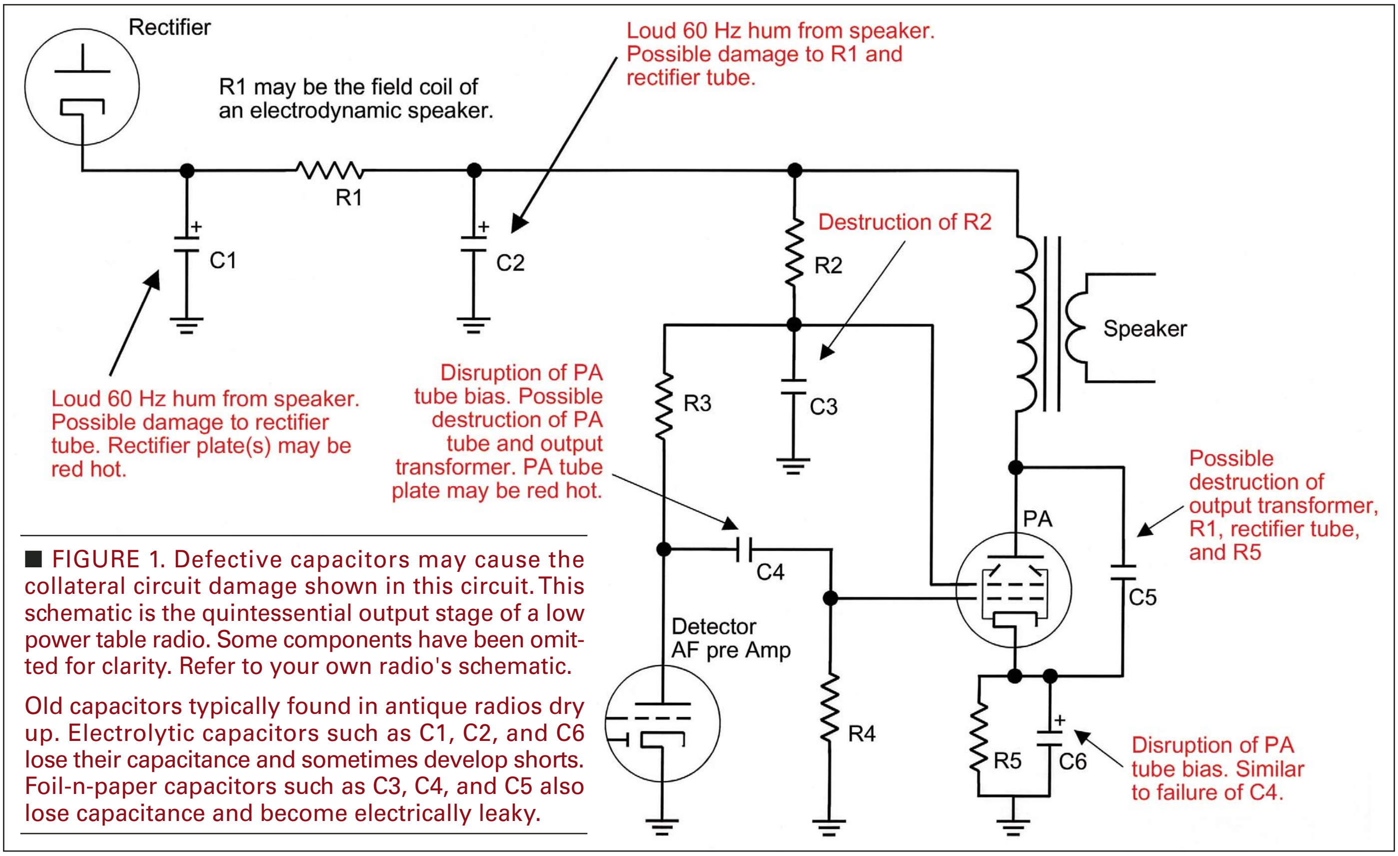
If you are new to restoration, start out with inexpensive radios. Start with radios that are in desperate need of restoration and have no historical value. Watch the eBay auctions and you will quickly learn which radios are sought after. For example, I would think twice before modifying a FADA 189 Catalin Bullet radio. This type of radio is a work of art. It is highly sought after and commands a price over US$2,000. Any modifications would spoil its value. These radios belong in protective display cases away from harm.

The Philco radio featured here is considered a middle-of-the-road set. It was only produced for one year, making it rather scarce. It took me over a year of on-and-off-again searching to find it. The design is elegant and surprisingly compact for a wooden radio. It is one of the few radios that has a finished back cover. This makes the radio ideal for placing on a desk where all sides are visible. On the negative side, this radio had moderate cosmetic damage. It suffered water damage, causing the laminations to part. The sides of the wood cabinet had swelled causing misalignment. After restoration, these defects are only visible upon close inspection.

Electrical Restoration

Most consumer electronics are designed to maximize manufacturer profits. Vacuum tube radios are no exception. The components — especially capacitors — used in these sets were chosen because they were inexpensive and gave a relatively long life. Unfortunately, they were never designed to last 65 years. This is not to say that all vacuum tube radios will need servicing. I have a Hammarlund HQ-150 receiver that works perfectly and has never been serviced. This radio is in a different league from the Philco. It is a high-end, commercial design that shares features with the best military equipment of the era.

The capacitors used in antique radios are almost exclusively paper foil

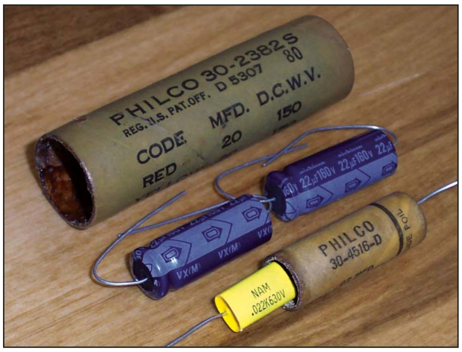


■ FIGURE 1. Defective capacitors may cause the collateral circuit damage shown in this circuit. This schematic is the quintessential output stage of a low power table radio. Some components have been omitted for clarity. Refer to your own radio's schematic.

Old capacitors typically found in antique radios dry up. Electrolytic capacitors such as C1, C2, and C6 lose their capacitance and sometimes develop shorts. Foil-n-paper capacitors such as C3, C4, and C5 also lose capacitance and become electrically leaky.

designs sealed in wax. You will be hard-pressed to find an original capacitor that is within specifications. The electrolytic capacitors will have lost much of their capacitance causing your set to hum. They may even be shorted causing instant circuit damage when the radio is energized. The coupling capacitors with their high leakage are just as bad.

It is worthwhile to investigate the collateral damage caused by faulty capacitors. The types of circuit damage are outlined in Figure 1. Ideally, you would never see this damage. But that would mean that the radio was never turned on. This is rarely the case.



■ PHOTO 3. New capacitors are physically smaller than their 1940's counterparts. It is possible to mount them in the old cases to preserve the original appearance.

Look on eBay where you will find the telltale descriptions. The Philco radio was no exception. Its eBay description read *"It works, picks up the local AM stations. There is a hum in the sound."*

Physically replacing the capacitors is an easy job. Modern capacitors are much smaller than the capacitors of yesteryear, as shown in Photo 3. The new capacitors are easily mounted under the chassis of the radio. If you want to preserve the original look of the radio, you can install the new modern capacitors into the original paper cases. Consider this option if you have a high-value collector's radio or if you truly want to maintain the original cosmetics of the set. The before and after pictures of the capacitor replacement are shown in Photos 4 and 5. I chose not to preserve the original look of the radio. However, I did save the old capacitors in case I change my mind.

You have two options for mounting the new capacitors. You can completely remove the old capacitor and install the new part. Alternatively, you can cut the old capacitor out leaving its connecting wires in place. The new part is then soldered to the old wire. Each method has its advantages. Removing the old leads looks better but could potentially damage the components the capacitor is soldered to, such as tube sockets or stand-off insulators.

The electrolytic capacitors used in tube radios typically have values from 10 to 100 uF. Under the old naming convention, you will see these components marked as MFD. Recall that electrolytic capacitors are polarity conscious. It in imperative that you install them correctly since they otherwise have a tendency to explode! Axial capacitors (shown in Photo 3) are preferred as the wire at each end stabilizes the component. Choose voltage ratings equal to or higher than the original. I used 160 VDC electrolytic capacitors in this radio. The actual capacitance value for electrolytic

capacitors is not critical, but do try to get close.

I have found that the values used in the old radios are still common today. The coupling and bypass capacitors are typically between 0.001 to 0.2µF. Film capacitors like those in Photo 5 are good substitutes. I use 600 VDC rated film capacitors for all my radios. You can purchase these capacitors from just about any electronics parts distributors.

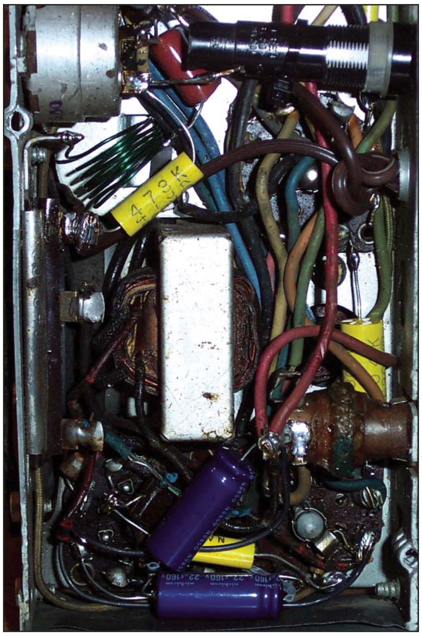
The Philco radio was one of the more difficult radios to service. It has a compact design for a set of this era. The set is so compact that the engineers mounted the second IF transformer on the underside of the chassis. This made replacing the components a challenge. The wire insulation used in this radio was problematic. The insulation had deteriorated resulting in exposed conductors in several locations. This problem only got worse as I poked around the chassis replacing the capacitors. In the end, I had to replace three short wire runs.

As a side note, do not replace the mica or ceramic capacitors. These capacitors are stable and rarely ever go bad. You should leave the can type electrolytic capacitors in place, but electrically disconnected.

I have performed this simple capacitor replacement surgery on dozens of radios. It has restored 95% of the radios to full operation. For the remaining 5%, the work was limited to the destroyed components outlined in Figure 1, dial cord replacement, and cleaning of the volume controls. I have only replaced a few tubes. It's actually quite amazing that the old tubes continue to operate as well as they do.

If you have a radio that is difficult to fix, you can find books at your local library. Antique Electronic Supply (**www.tubesandmore.com**) is an excellent source of tubes, electrical components, and many cosmetic components. They also sell reprints of radio schematics. The Internet is a good source of information. If you look hard enough, you may be able to find your radio's schematic. Radio clubs are another resource for assistance in repairing your radio set.

■ PHOTO 4. The original state of the chassis wiring before modifications. The capacitors are recognized as the large, brownish yellow components. This radio was repaired sometime in the past as evident by the non-original "Olson" brand capacitor.



■ PHOTO 5. After the electrolytic capacitors have been relocated (lower part of the picture). The bright yellow components are the metal film coupling and bypass capacitors.

Physical Restoration

The decision to strip and refinish this radio was an easy one. The Philco PT-44 had suffered water damage and had lost over 50% of its original finish. The parting laminations had left additional gaps. Luckily, the radio had a simple design and used good quality veneer. This radio did not have a decal or any other feature that would be lost if the set was stripped. The bottom of the set was left untouched, thereby preserving the paper tube diagram and model number identification tag.

The first part of the physical restoration is performed during the electrical restoration. I used water and isopropyl alcohol to clean the Philco chassis while it was out of the cabinet. Q-tips and a toothbrush are the cleaning instruments of choice. The tubes were cleaned with a damp cloth. It is desirable to keep the original printing on the tube envelopes so be extremely gentle when cleaning tubes.

The wooden cabinet was cleaned with a brush, then a damp cloth. The loose laminations were then glued back into position using wood glue. Clamping the lamination on this curvy cabinet required ingenuity. A "C" clamp and many heavy books were enlisted in the process. The plastic dial covering was removed along with the cloth speaker cover.

The chemicals to refinish the wood cabinet were purchased at a home supply store. The radio was stripped using KLEAN-STRIP's Klean Kutter Refinisher (**www.klean strip.com**). This is a mild chemical that removed the old finish as advertised. I used a cheap paint brush and a scouring pad to apply/remove the stripper. Most of the original stain remained. The radio was sanded using 200 grit sanding paper to remove all traces of the original finish, as seen in Photo 6. The radio was stained using MINWAX's Early American 230. A soft rag was used to apply the stain. Finally, the radio was finished using three coats of DEFT's Clear Wood nitrocellulose Brushing Lacquer. A good quality paintbrush was used to apply the finish. The cabinet was buffed with #0000 steel wool between applications.

There is one final point I want to make concerning the Philco PT-44. This radio could be considered hazardous waste due to its asbestos content! As I've mentioned several times, this radio is one of the more compact wooden radios you will find. The designers of this set must have been concerned about overheating because they installed what looks like an asbestos liner underneath the chassis. I have chosen to leave the pad intact. Asbestos isn't a problem if

■ PHOTO 6. Wooden cabinet stripped, sanded, and ready for staining.

you leave it alone. It's only hazardous when it is disturbed and becomes airborne.

The pad is entirely underneath the chassis so it won't be disturbed until the radio is serviced again in the distant future. I could have sealed the pad with lacquer, but felt the fire danger was greater than the asbestos danger. After all, the pad is there for a reason.

Locating Antique Radios

Locating antique radios is getting harder every year. You used to be able to pick them up at yard sales, flee markets, and auction sales. When I was a child, my father would purchase tube radios for me to tinker with at the Salvation Army. These supplies have all but dried up.

Today, online auctions are a great place to purchase a radio. In fact, it appears that eBay sets the market prices. The only problem with eBay is the freight charges you must pay to have your radio delivered. Another place to purchase radios is at swap meets hosted by your local radio club. Chances are there is a radio club in your nearby community. This is also a great place to learn more about radios and meet people who share a common interest. Antique stores occasionally have radios for sale.

If you are new to radio restoration, try to purchase radios from the late '30s to early '50s. Radios earlier than this are hard to repair as the individual component's construction was different than we are used to. Capacitors were often potted affairs with multiple hard-to-identify wires. The radios from the '20s were almost exclusively battery-powered. You can't purchase 45 and 90 volt batteries anymore ... in the early '60s, radios started to use printed circuit cards and circuit modules. These do not lend themselves to restoration.

Closing

This completes the restoration of the Philco PT-44. This radio has an elegant look and a nice sound. I hope it survives another 65 years! Perhaps one of my sons or future grandchildren will appreciate it. Just remember to listen to my warning and be careful with any radio you restore!

P.S. Happy centennial to the vacuum tube. One hundred years ago this November, Lee de Forest invented the triode. **NV**

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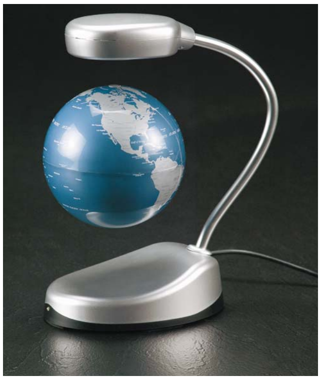

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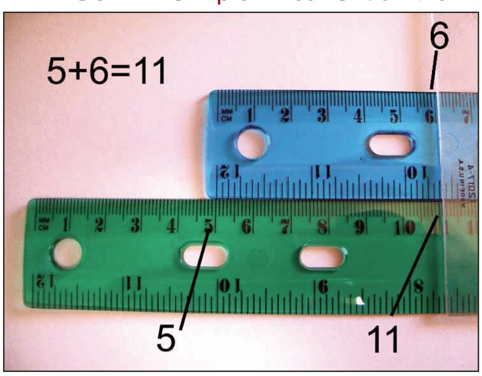
In 10 years, your computer will be in the landfill, but your slide rule will be operating just as fast as it did in 1700. As an engineer from the 1970s, I have a nostalgic place in my heart for those pre-electronic computer mechanical calculators.

AN ELECTRONIC SLIDE RULE

What is a Slide Rule?

The slide rule (often called a "slipstick") is a mechanical analog computer, consisting of at least two finely divided scales (rules), most often a fixed outer pair and a movable inner one, with a sliding window called the cursor. Before the advent of the pocket calculator, it was the most commonly used calculation tool in science and engineering. The use of slide rules continued to grow through the 1950s and 1960s even as digital computing devices were being gradually introduced; but in the early 1970s, the pocket electronic calculator made slide rules largely obsolete and most suppliers exited the business.

■ FIGURE 1. Simple Linear Slide Rule.



Simple Slide Rule Example

Let's look at the simplest example of a slide rule. We will make a simple adding slide rule from two 12 inch rulers marked in millimeters. If we line the rulers up as shown in Figure 1, we can add small numbers. From the ruler, we see that 5 + 6 = 11. While the linear rule is useful as an example for addition or subtraction, the real break for slide rules occurred in 1614 when John Napier — a Scottish scholar — invented the logarithm.

Logarithms

In order to understand how slide rules can multiply and divide, we must investigate logarithms. A logarithm is just an exponent. For example, the logarithm of a number x to a base *b* is just the exponent you put onto *b* to make the result equal x. For instance, since $3^2 = 9$, we know that 2 (the power) is the logarithm of 9 to base 3. Symbolically, $\log_3(9) = 2$. More generically, if $x = b^y$, then we say that *y* is "the logarithm of x to the base b." In symbols, $y = \log_b(x)$. Every exponential equation can be rewritten as a logarithmic equation, and vice versa, just by interchanging the *x* and *y* in this way. Commonly used bases are 10 and e. Logarithms that use e as the base are known as "natural" logarithms and are written as ln. Base 10 logarithms are written as log. For the natural logarithm, we can write the relationship $e^x = y$ and $x = \ln(y)$.

But what is this "e?" Numerically, e is about 2.7182818284; "e" (like pi) crops up in all sorts of places. Perhaps its first use was in the computation of compound interest. Babylonian tablets from 1700 BC ask

■TABLE 1. Approximations to "e."

N	(1+1/N)^N
1	2.000000
10	2.593742
100	2.704814
1000	2.716924
10000	2.718146
100000	2.718268
1000000	2.718280

EQUATION 1

Savings = Principal(1+Interest Rate/Compounding Period)^(Compounding Period*Time)

"how long does it take to double your money at 20% interest compounded yearly?" Or $1.2^x = 2$ and what is x? Equation 1 shows how this can be generally written.

Consider the case where we have a 100% interest rate, a one year time period, and the number of compounding periods goes to infinity. Equation 2 shows how this can be written.

EQUATION 2

Savings = (1 + 1/N) ^ N

where N approaches infinity

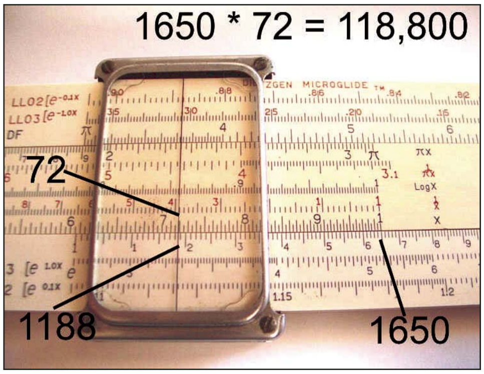
Work this out in an Excel spreadsheet and you will see that Savings approaches 2.7182818284 as Compounding Period (N) approaches infinity as shown in Table 1. [1]

"e" and natural logarithms occur throughout nature. The decay of radioactive nuclides is governed by $e^{-\lambda t}$ where λ is the decay constant related to the half life of the nuclide and t is the time. Of interest later in this article is the relationship between the voltage and current through a diode.

Slide Rule History

What makes the invention of the logarithm important to the history of the slide rule is the property that multiplication and division of numbers can be performed by adding or subtracting their logarithms. In the example above, we saw that we could perform simple additions or subtractions using a linear scale. With a logarithmic scale, we can perform multiplication or divisions!

In 1620, Edmund Gunter of London made a straight logarithmic scale and performed multiplication and division on it with the use of a set of dividers. In about 1622, William Oughtred — an Anglican minister who is today recognized as the inventor of the slide rule — placed two such scales side by side and slid them to read the distance relationships, thus multiplying and dividing directly. In 1675, Sir Isaac Newton solved cubic equations using three parallel logarithmic scales and made the first suggestion toward the use of a cursor. Figure 2 shows a modern slide rule with a sliding cursor. You can tell it is modern because it has microglide™ Teflon groves.

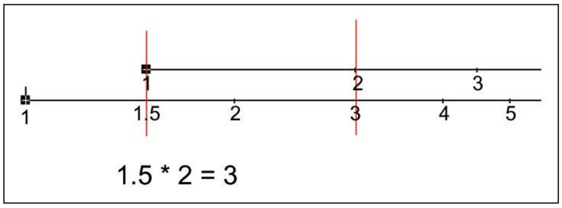


■ FIGURE 2. A Modern Logarithmic Slide Rule.

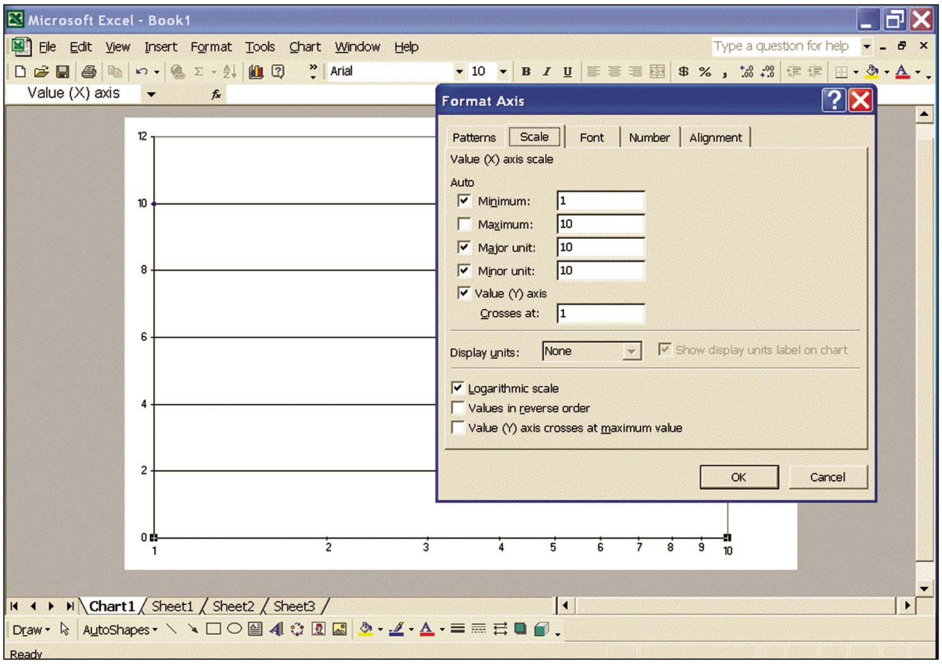
Decimal, Decimal, Who's Got the Decimal Point?

Figure 2 shows a modern slide rule in the process of multiplying 1650 x 72. As you can see, the result is 1188. This was the problem with slide rules. Although the slide rule gave you the answer to three or four significant digits, it did not give you the location of the decimal point. So the answer might be 1188, 11880, 118800, or 1188000 for that matter. Engineers used several methods of determining where to place the decimal point.

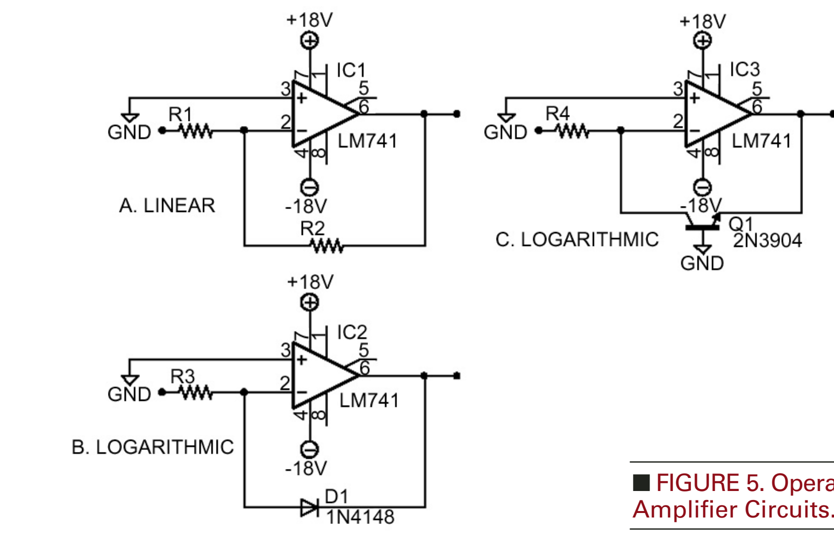
The first method was approximation. In the example here, 1,500 times 100 is 150,000, so we can estimate that the correct answer is around 150,000 and the slide rule tells us that it is, in fact 118,800. Another method was based on using scientific notation. Write both numbers in scientific notation 1.65E3 and .72E2. Looking at the product of the numbers — about 1.5 times 1 — we would expect a number less than 1.5. Adding the exponents



■ FIGURE 4. Rudimentary Slide Rule for Multiplication and Division using Excel Logarithmic Scales.



■ FIGURE 3. An example of an Excel Generated Logarithmic Scale.



■ FIGURE 5. Operational Amplifier Circuits.

(because this is a multiplication) we get 3 + 2 = 5. Using the slide rule, we get the product as 1.188 and the power of 10 is 5 or 1.188E5, or 118,800.

Build a Mechanical Slide Rule

One can construct a simple slide rule that will multiply and divide from a couple of sheets of logarithmic graph paper. If you have a computer, Microsoft Excel can be used to generate a logarithmic graph as shown in Figure 3. By laying the logarithmic scales next to each other, we have a rudimentary slide rule as shown in Figure 4 for multiplication and division.

An Electronic Slide Rule?

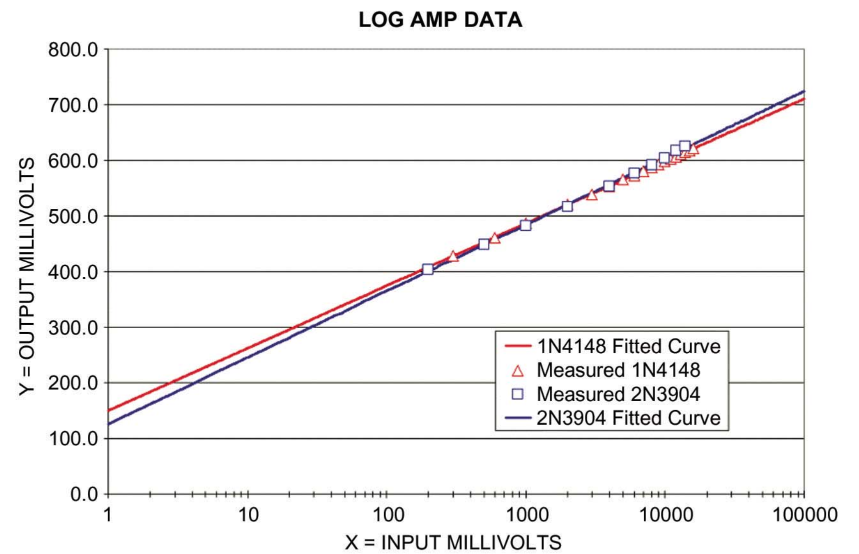
There are electronic equivalents to the linear and logarithmic slide rules. Many people are familiar with the linear response from an operational amplifier shown in Figure 5A. By using a semiconductor diode, we have a device that has a logarithmic relationship between the voltage applied to it and the current flowing through. As the applied voltage across the semiconductor diode increases linearly, the current through it increases exponentially. By using the circuit shown in Figure 5B, we can generate a logarithmic relationship between the input voltage and the output voltage as shown in Figure 6.

The inherent internal resistance causes a practical problem with using a simple diode in the logarithmic amplifier. The resistance is subject to change with temperature. This diode effect can be reduced by using an NPN transistor as shown in Figure 5C. The relatively high base resistance of the transistor will be bypassed as most of the emitter current flows through the collector region of the transistor.

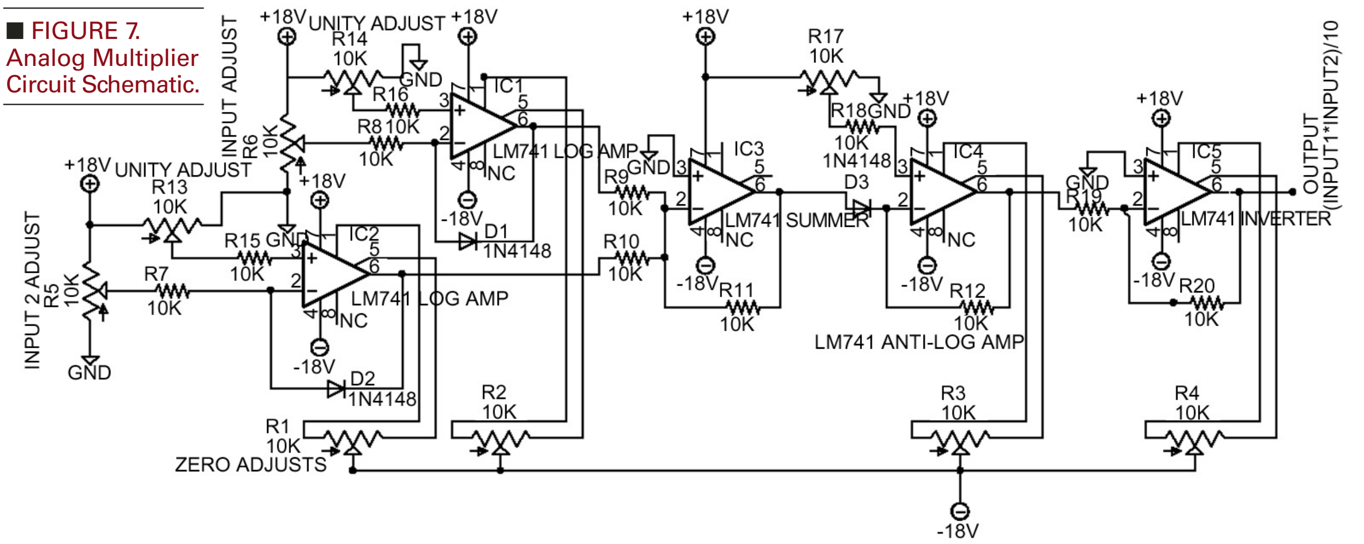
Figure 6 also shows the data compression feature of the logarithmic amplifier. The inputs range from 100 to 10,000 mV on the input which is compressed to 374 to 598 mV on the output scale. This data compression characteristic is especially useful where the inputs vary over a wide range of values, for example in a nuclear power plant where the neutron flux can range over many decades from when the reactor is shut down to 10^{12} neutrons/cm^{2}sec when the reactor is operating. The logarithmic amplifier is also useful in compressing the input data range before analog-to-digital conversion.

So how can we construct the electronic equivalent of the slide rule? Well, we can use two logarithmic amplifiers — IC1 and IC2 — to convert two voltages to the logarithm of the voltages. Next, we can sum or subtract the voltage logarithms using IC3. This is the equivalent of multiplying or dividing the voltages. We can use an anti-logarithmic amplifier — IC4 — to convert the sum of the logarithmic voltages back to voltage. Finally, since each amplifier stage reverses the sign of the output with respect to the sign of the input, another amplifier — IC5 — was added to reverse the negative sign of the anti-logarithmic amplifier output to make the sign of the output positive. This analog multiplier is shown schematically in Figure 7.

You can get the functionality of the analog multiplier shown in Figure 7 in a single eight-pin device: the Analog Device AN633 shown in Figure 8. The AD633JN is a four quadrature multipli-



■ FIGURE 6. Logarithmic Amplifier Input and Output.

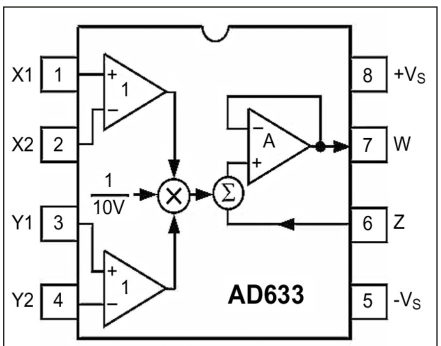


■ FIGURE 7. Analog Multiplier Circuit Schematic.

er which means that the output will be of the correct sign. The AD633JN is laser calibrated to an accuracy of 2% of full scale so there is no need for the calibration potentiometers when using the AD633JN. The AD633JN also includes a scaling factor of 1/10V on the output so larger input values can be multiplied. The AD633JN price is competitive at about $7 since it replaces five op-amps and a number of calibration potentiometers.

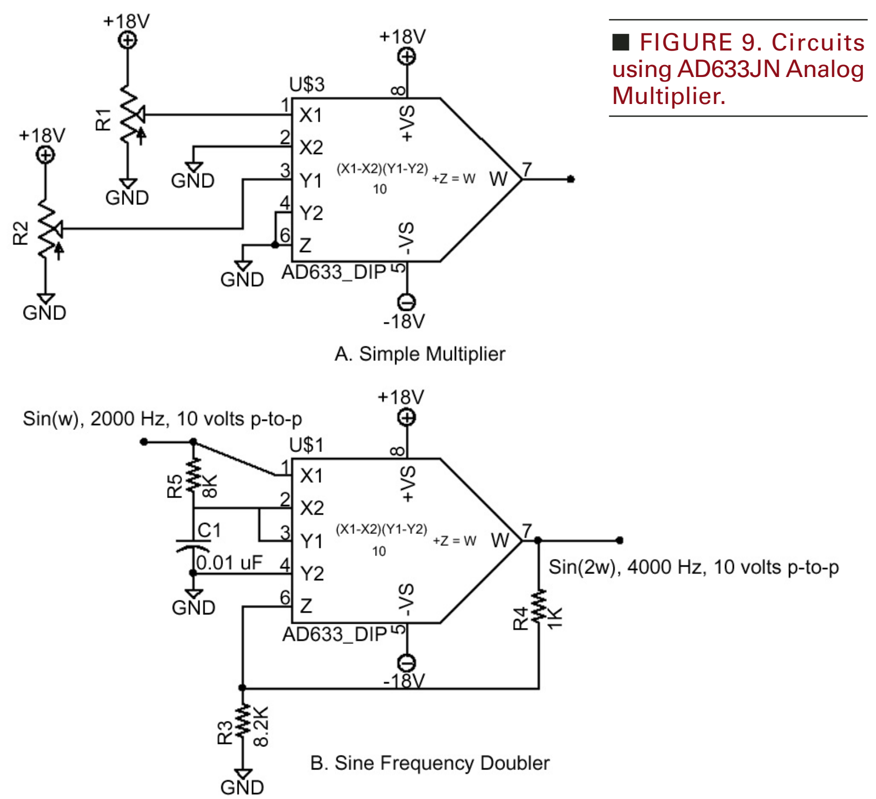
Let's do a simple exercise using the AD633JN analog multiplier and the circuit shown in Figure 9A. Adjust R1 until 1.65 volts is measured at pin 1 and adjust R2 until 7.2 volt is measured at pin 3. The output should be 1.188 volts at pin 7. Remember there is a 1/10 multiplier on the output. Thus, we have recreated electronically the multiplication done previously on the slide rule.

■ FIGURE 8. Functional Diagram for AD633JN Analog Multiplier.

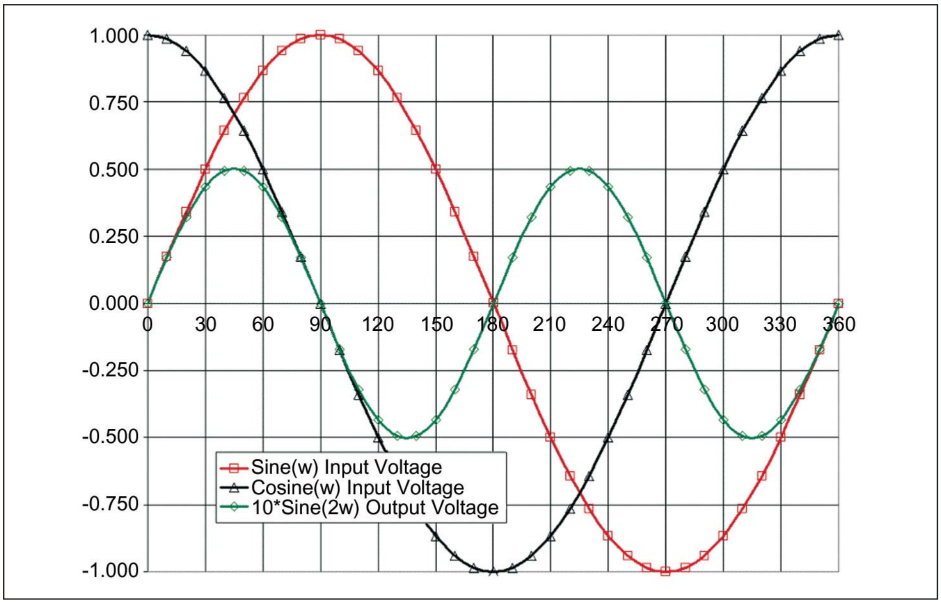


Analog Multiplier Uses

While it is interesting to recreate the slide rule electronically, analog multiplication has several real-world applications. One application of the analog multiplier is as a frequency doubler. The frequency doubler uses the trigonometric relation: 2 sinθ * cosθ = sin 2θ. If we multiply the sine and cosine of the fundamental frequency, the output will be a sine wave that has twice the fundamental frequency. The sine and cosine waves have the same shape, but are 90° apart in phase. We can take the input sine signal and shift it by +45° and -45° using an RC circuit to obtain the desired sine and cosine. The inputs and the output (product of the inputs)



■ FIGURE 9. Circuits using AD633JN Analog Multiplier.



■ FIGURE 10. Inputs and Output (sine*cosine) of Frequency Doubler Circuit.

of the circuit are shown in Figure 10.

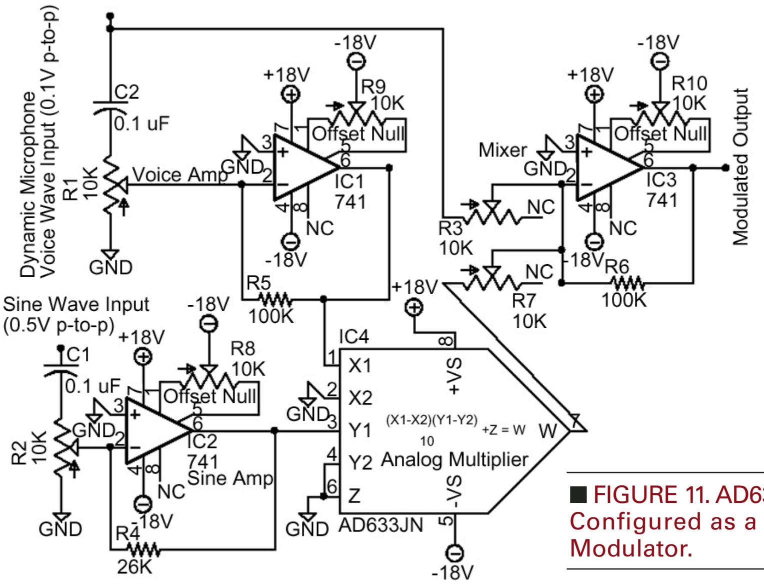
The circuit is shown in Figure 9B. Note that only one RC circuit is necessary, since we have both inverting and non-inverting inputs available for each factor. R5 and C1 must be chosen to suit the operating frequency, but the doubler is fairly broadband, and will work over a range of frequencies. Use the equation FREQUENCY= 1/(6.283*R5*C1) to calculate R5 or C1. For 2 kHz, R5 = 8K and C1 = 0.01 µF will work. The 1K and 6.8K resistors on the output are for adjusting the amplitude back to the 10 volt peak-to-peak of the input. The function of the AD633JN is expressed as V = (X1 - X2)*(Y1 - Y2)/10 + Z. The power supply can be from ±8 to ±18 V.

Another interesting application of the analog multiplier is the ring modulator. In the previous frequency doubler circuit, the behavior is based on a trigonometric relationship and the circuit will only double the frequency of a sine wave. Other wave forms will result in unpredictable results. Unpredictable results can be interesting! Ring modulation is an audio effect performed by multiplying two audio signals. Ring modulators were a common feature on early Moog synthesizers [4]. In 1963, the BBC Radiophonic Workshop used ring modulators to produce the distinctive "EX-TER-MI-NATE!" voice of the alien Daleks in the television series *Dr. Who*. The original Dalek voice was a human voice ring modulated with a 30 Hz sine wave and then further processed. Figure 11 is a circuit for a ring modulator using the AD633JN analog multiplier. I found that I got an interesting Dalek-like output by using a 3,000 Hz sine wave. The completed Dalek voice circuit is shown in Figure 12 and Table 2 contains a parts list.

The voice wave input can be the output of a dynamic microphone. Potentiometers R1 and R2 control the amount of voice and sine wave sent to

Part	Value	Description	Source
R5, R6	100K	1/4 Watt Resistor	Reference 3
R4	26K	1/4 Watt Resistor	Reference 3
R1-R3, R7-R10	10K	Multi-turn Potentiometer	Reference 3
C1,C2	0.1µF	Mylar Capacitor	Reference 3
IC1, IC2, IC3	741	Op-amp	Reference 3
IC4	AD633JN	Analog Multiplier	Reference 3

■ TABLE 2. Parts List for Analog Multiplier Ring Modulator.



■ FIGURE 11. AD633JN Configured as a Ring Modulator.

REFERENCES

■ [1] Maor, Eli, *e: The Story of a Number*, 1994, Princeton University Press.

■ [2] Carr, Joseph, *Linear IC/Op Amp Handbook*, 1983, Tab Books.

■ [3] Jameco Electronics at **www.jameco.com**.

■ [4] Ring modulator discussion and sound samples at **www.harmony-central.com/Effects/Articles/Ring_Modulation/**

the multiplier. R7 controls the gain and the amount of modulated sine wave in the output. R3 controls the amount of un-modulated voice in the output. The offset null potentiometers, R8, R9, and R10 are used to zero the outputs of the op-amps when the inputs are zero.

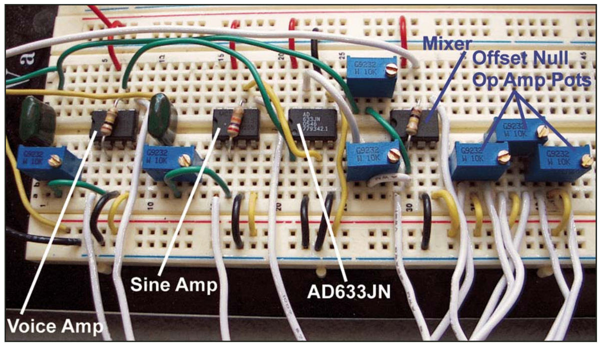
Decline of the Slide Rule

While logarithmic amplifiers may be alive and well, the death toll for the mechanical slide rule began when Hewlett-Packard engineers started to develop a scientific calculator so small that it could fit in a shirt pocket. Four years later — in July of 1972 — the HP-35 scientific calculator, was born ... and slide-rule usage began to decline. With the HP-35, you no longer had to try to keep track of the decimal point location and it was accurate to 10 digits.

The HP-35's original price was $395. The market of pocket calculators exploded during 1972 through 1974. Dozens of manufacturers and hundreds of models appeared around the world during that period. Now that computing capability can be found at the "everything for a dollar" store. In 1975, Keuffel & Esser — one of the major manufacturers of slide rules — manufactured its last slide rule. The slide-rule continued its decline into obscurity.

We've taken a trip down memory lane with the slide rule and have looked at the electronic equivalent. We have explored a couple of applications of logarithmic amplifiers, namely the frequency doubler and the ring modulator. Today's technological buzzwords include "portable," "multifunction," "energy efficient," and "always-on." The sliderule reminds us that old technology can sometimes meet today's buzzword criteria. **NV**

■ FIGURE 12. AD633JN Ring Modulator Circuit.

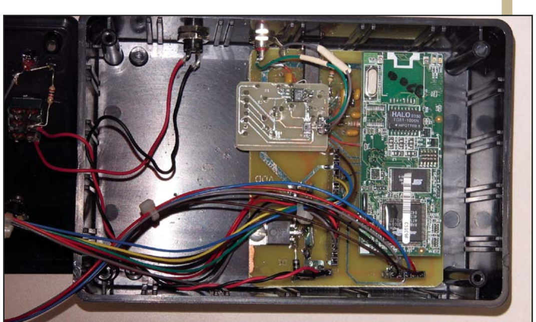


■ FIGURE 13. The HP-35 Slide Rule Killer. Photo courtesy of The Museum of HP Calculators.

Direct Digital Synthesis (DDS) is one of the more prevalent methods used to generate a frequency agile signal today.

The material in the following explanation was taken from www.ehb.itu.edu.tr/~eepazarc/ddstutor.html. If you want to search the Internet for more information on DDS, I suggest you use the full name as the search criteria otherwise you will get lots of hits on dentistry!

■These photos show the DDS unit.



STAND-ALONE DDS UNIT

One of the ways DDS differs from both phase locked loops and mixing techniques is that the output is generated by a digital-to-analog (D/A) converter. There are four basic components to a DDS system:

1. Crystal oscillator
2. Phase accumulator
3. Look-up table
4. D/A converter

The crystal oscillator defines the highest frequency capable of being generated by the system. The DDS covers an operating range limited by sampling theory (Shannon, Nyquist). The highest practical output frequency is about 45% of the crystal oscillator frequency. One of the main advantages of a DDS system is that the method of constructing the output signal is almost entirely digital, and the precise amplitude, frequency, and phase are known and controlled at all times. Among the advantages of a DDS system are:

1. Very fine tuning steps
2. Very fast switching time
3. Phase continuous frequency change
4. Low phase noise

The November '05 issue of *QST* had an article on a DDS device controlled by a PC. After reading it, I determined that it might not be very difficult to build a stand-alone unit. I now have a DDS unit which is controlled by an RCM3610 by Rabbit Semiconductor. The DDS unit has the following characteristics:

1. A two line LCD for a menu display
2. Push button switches to step through the menus
3. Powered by a 7-15 VDC wall wart
4. The following is programmable:
   - Frequency in 1 Hz steps from 1 Hz to 10 MHz
   - Phase
   - Wave form — sine, triangle, square
   - PSK and FSK
   - Frequency sweep with pause
   - Amplitude of sine and triangle waveforms

The system consists of two printed circuit boards. The first is the main board with the processor, LCD, switch interfaces, and the DDS circuit. The second board has the programmable attenuator and output buffer.

There are three push button switches in the design. Only two are used to navigate the menu system. PB3 is not used — it is available for future expansion. SW2 — a toggle switch — is used when the PSK/FSK mode is selected. It is the method of switching between the two frequencies and/or phases. This method allows you to put a connector in parallel with the switch in order to implement an external method of control.

The Microprocessor

Refer to Figure 1. I chose the RCM3610 as the control device

mainly because I am quite familiar with it. It is programmed in both C and assembly language. It has quite a few parallel output bits, as well as several serial I/O ports. The parallel I/O is used for the LCD, switches, and Chip Select signals.

Two resistor packs terminate unused inputs, as well as providing pullups for the switches. When the microprocessor on the RCM3610 comes out of its reset state, all of the I/O pins which can be inputs are set as inputs. All inputs on a CMOS device should be terminated to either ground or VDD. Floating inputs can cause localized damage to the device.

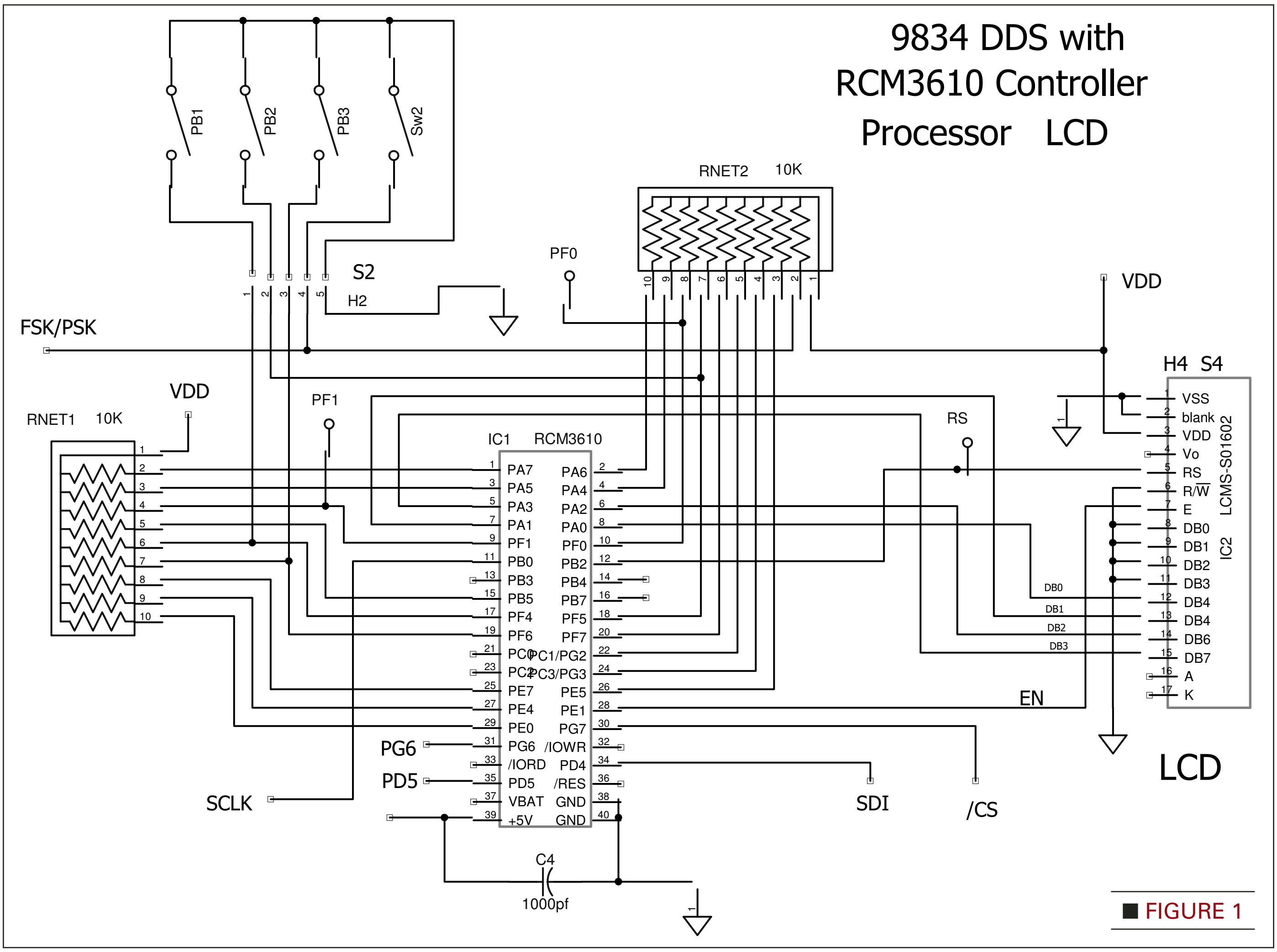
The interface to the LCD uses a feature of the processor which allows you to expand the parallel I/O capability by up to 64K bytes. This feature enables the program to access the external devices in essentially the same way as you would access the internal parallel I/O ports. Parallel Port A becomes the data bus, Parallel Port B bits 2-7 become address bits, and bits from Parallel Port E are I/O strobes. Since I am never reading anything from the LCD, its interface only needs to use a single address bit (PB2) in order to select between either the control register or the data register.

The interface to both the DDS and attenuator ICs use SPI (Serial Peripheral Interface). This is a relatively high speed serial communications method which is used by many peripheral ICs. You will find many other ICs which use it — A/Ds, D/As, memories, etc. The April '06 issue of *NV* has a good article discussing SPI.

In the general case, each IC requires four signals: Clock, Data In, Data Out, and Chip Select. Neither of the SPI devices in this system sends any data back to the processor so they do not have a Data Out. Each device must have its own Chip Select, the other signals are shared. Only the device with the active Chip Select will communicate with the controlling processor.

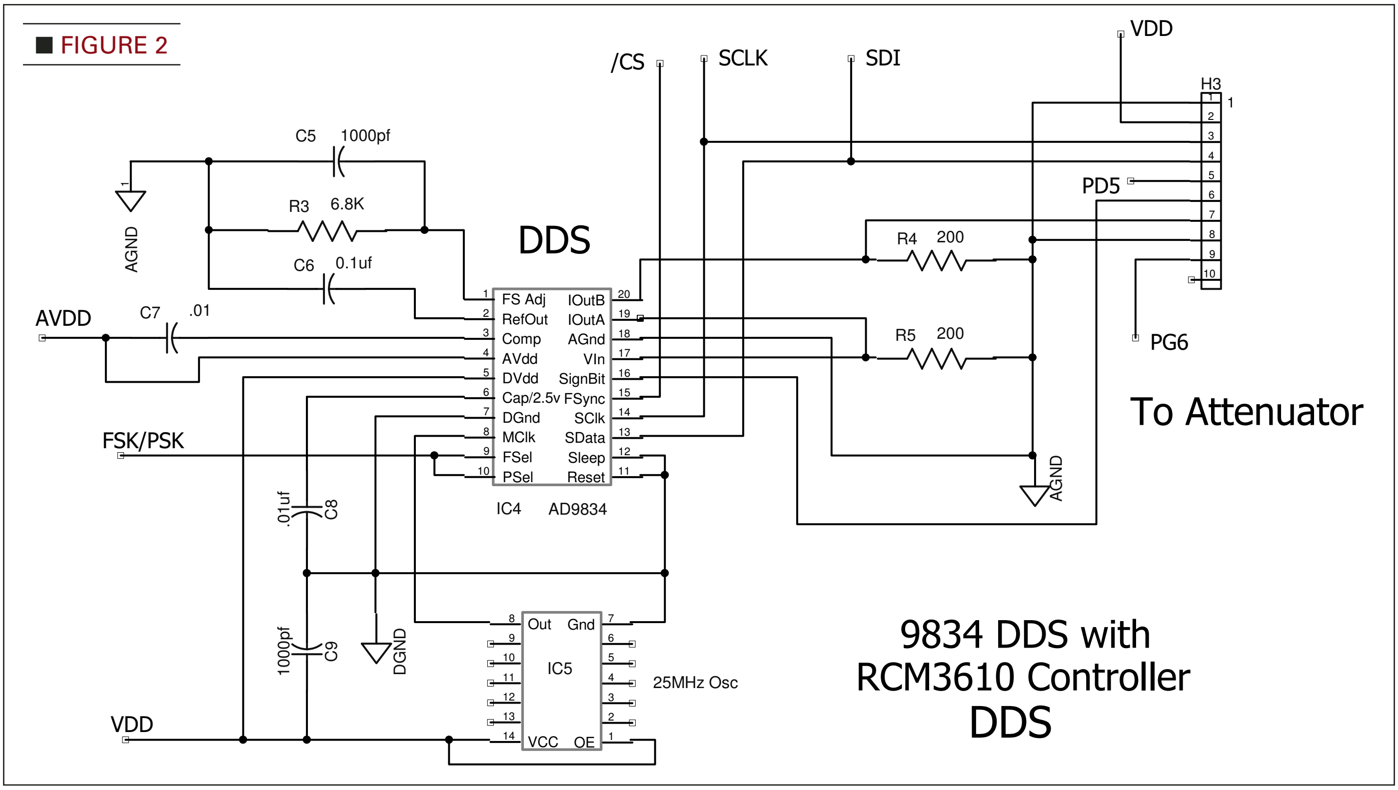
The LCD

The LCD has an S6A0069 controller which is compatible with the industry standard HD44780. I chose to use the four-bit interface to the LCD because I eventually want to



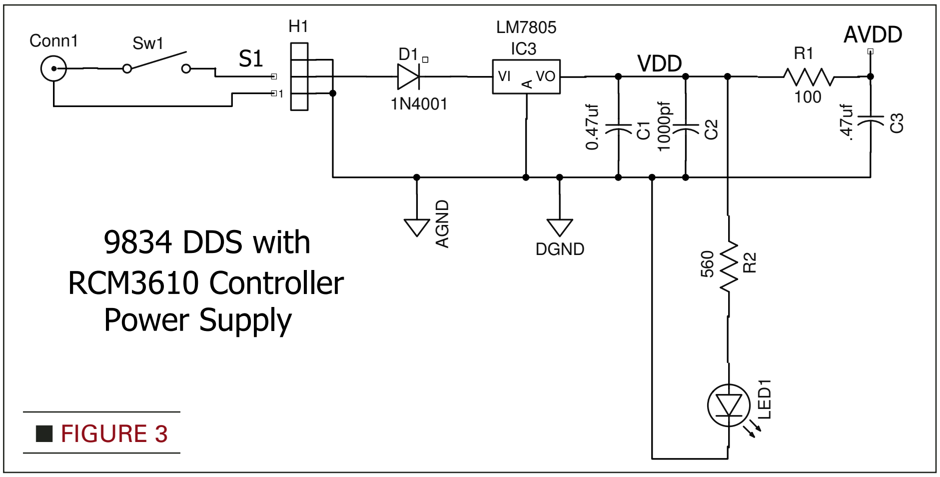
■ FIGURE 1

■ FIGURE 2



try to build the device using a low pin-count PIC. You can see from the schematic that there are two control lines being used: Enable and Register Select. The Control Strobe from Port E bit 1 is set up as a Write Strobe to drive the Enable input. The Register Select is driven from Port B bit 2 which is I/O address bit 0. I am not using the read capability so I have the Read/Write grounded to permanently enable its Write operation.

I chose a two-line, 16 character device in order to get a low-cost display. I also wanted to choose an LCD which can be easily obtained by anyone who wants to build the unit. However, I have since found some two-line, 20 character LCDs which are relatively inexpensive. For those who want to enhance the menu system, it would be fairly easy to use a four-line LCD instead. The pin-out for most character LCDs is common so you can probably use almost any unit, as long as it uses an HD44780, or equivalent, and is at least two lines of 16 characters each.



■ FIGURE 3

The DDS

Refer to Figure 2. The main output of the circuit comes from IOutB which goes to the Attenuator board. This output can be either a sine or triangle wave signal. The output of the internal D/A is 3 mA full scale. With a 200 ohm load (the recommended value), this yields a 600 mV peak-to-peak signal.

IOutA drives an internal comparator, the output of which can be steered to the SignBit output. This output is a square wave which can be programmed to select from among three signals: comparator output, sign bit of the internal D/A, or sign bit divided by two. The current system design does not make use of this signal, but it is available on the interface connector to the Attenuator board for anyone who wants to use it.

The main clock — which is used to generate the output signal — can be any frequency up to 50 MHz. I chose 25 MHz mainly because I was originally going to use an AD9833, a lower frequency device. However, I had trouble obtaining one from Digi-Key. The 9834 was readily available, so I

changed my design to use it instead.

The DDS can generate any frequency up to one half the main clock (Fosc) in steps of Fosc/2^{28}. This is because the DDS uses a 28 bit phase accumulator. With the 25 MHz oscillator, this yields steps of about 0.1 Hz. The highest practical sine wave output is about 1 MHz. Higher frequency signals do not look much like sine waves.

The Attenuator Board

My initial design did not have any means to control the amplitude of the output signal. I decided to implement an amplitude control circuit after showing my prototype to a few friends at work (Figure 4). The circuit consists of three sections: an inverting amplifier to get the signal up to a higher level, a programmable attenuator, and a voltage follower.

The inverting amplifier has a gain of approximately five — fixed by the ratio of R8/R7. Since the signal is applied to the inverting input, I had to add an offset circuit — R9 and R10 — to insure that the output signal stays in the linear range of the op-amp. With these component values, the output voltage ranges from about one volt to four volts. To keep the design simple, I decided to not implement any kind of adjustments.

The attenuator consists of a programmable potentiometer and voltage follower. The AD5200 is programmable in 256 equal steps with an end-to-end resistance of 10K. The program allows you to set the "wiper" to any of the 256 positions. This yields a step size of 3V/256, or approximately 12 mV. It would be fairly easy to modify the program to allow you to program in dB or millivolts. By changing the ratio of the gain resistors, you can easily change the maximum peak-to-peak voltage. If you change the gain, you will need to change the value of at least one of the offset resistors. An option which may be of interest is to make the maximum output voltage 0 dBm. When driving 600 ohms, 0 dBm is 0.7746 volts. This is equivalent to about 2.19 volts peak-to-peak, which is very close to the output voltage of my circuit. By reducing the gain to a factor of 3.65 (instead of 5), you will get a maximum output voltage of 0 dBm. You might also then want to change the output resistor (R11) from 200 ohms to 600 ohms, so you have a 600 ohm output impedance.

The Program

I have been using SPI devices for many years, but still managed to overlook a very important "feature" of SPI. There are four modes of SPI which define various phase relationships between the clock and data signals. As it turns out, the DDS uses one mode and the attenuator IC uses a different mode. At first, I did not realize this — mainly due to not reading the specs carefully enough. The program now changes the SPI mode when entering the attenuator function and then restores it to the mode required by the DDS when exiting.

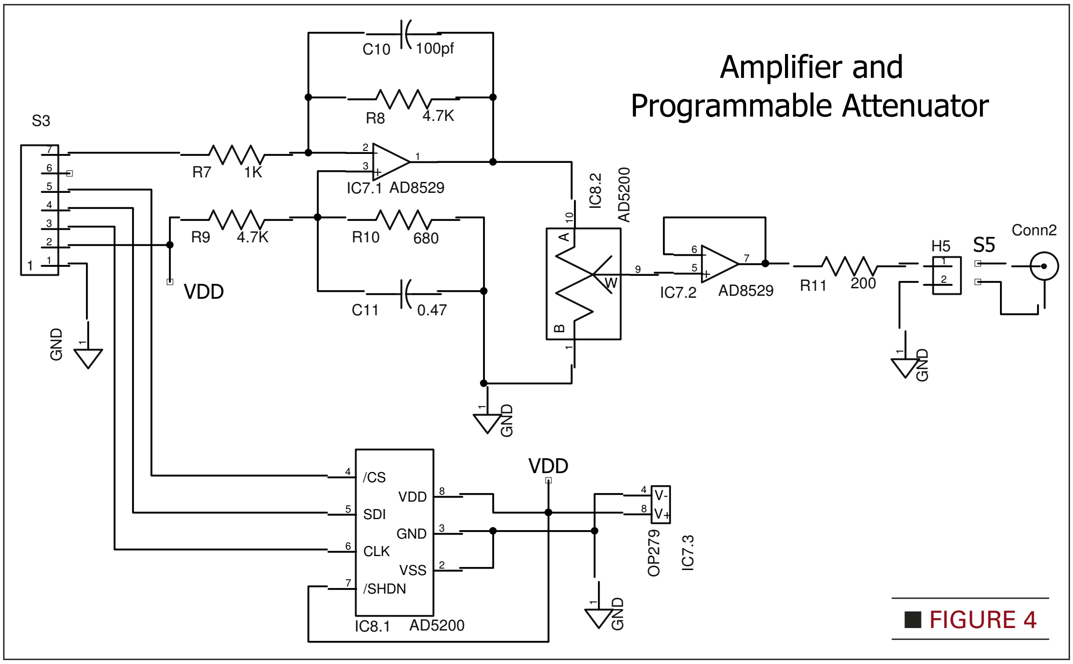
The main parts of program are contained in two files: AD9834.C and AD9834.LIB. I also use a serial library — FSER.LIB — for the SPI communications. You will find that the source files (available on the *Nuts & Volts* website at **www.nutsvolts.com**) are fairly well commented and should be relatively easy to follow. Most of the code is in C but there are some functions partially in Assembly language.

The Menu

When not changing a parameter via the menu, the display will show the current frequency and phase values, as well as indicating the current mode and waveform. There are not enough characters in the display I used to also display the amplitude.

The menu system uses a two line, 16 character-per-line LCD and two push button switches. I found this to be adequate for my needs and it does allow you to easily set up the unit. Following is a brief description of the menu and how to navigate it. The main menu consists of the following options:

1. F0 — Change Frequency 0
2. F1 — Change Frequency 1
3. P0 — Change Phase 0
4. P1 — Change Phase 1
5. Waveform
6. Mode of Operation
7. Amplitude



■ FIGURE 4

The Main menu is entered by pressing PB1. Generally, PB1 is used to step through the menu selections and PB2 is used to select the one you want. You can either hold PB1 or press and release it. Each press and release will advance to the next menu item. If you keep it pressed, the system will advance through the selections at one-second intervals. The menu will wrap around to the first item if you hold the switch past the last one. Pressing PB2 — after releasing PB1 — tells the system to select the currently displayed menu item.

For the Frequency, Phase, and Amplitude selections, the current value will be displayed and the cursor will be placed on the most significant digit. Press and release PB1 to advance the cursor to the next digit. Holding PB1 will cause the cursor to continue to advance through the digits with a one second delay between each until PB1 is released. Once the cursor is on the digit you want to change, just press and release — or press and hold — PB2 until the desired digit value is displayed. Using PB1 to advance past the last digit will cause the displayed value to be programmed into the system when PB1 is finally released.

The Waveform and Mode menu operations are similar to the Main menu operation. PB1 is used to step through the available options. PB2 is used to select the desired option.

The values in () are what shows in the status display.

The Waveform menu has the following options:

1. Reset (RE) — Turns the output off
2. Sine (SI) — Sine wave
3. Triangle (TR) — Triangle wave
4. Square (SQ) — Square wave the same as the selected frequency
5. Square/2 (S2) — Square wave generated by the sign bit of the D/A, effectively half of the frequency

The Mode menu has these options:

1. CW-F0 (CW) — Continuous wave of F0 and Phase 0
2. CW-F1 (CW) — Continuous wave of F1 and Phase 1
3. FSK/PSK (FS) — Enable FSK/PSK using SW2 or an external switch
4. Ramp 1 (R1) — Ramp from F0 up to F1, jump back to F0 and start over
5. Ramp 2 (R2) — Ramp from F0 up to F1, then ramp down to F0 and start over

For the Ramp modes, you are asked to enter both a step size and a delay value. The step size is in 1 Hz increments. The delay is in one millisecond increments up to 99 seconds. You can pause the Ramp at any time by pressing PB2. When paused, the LCD will show the current frequency of the ramp. Press PB2 again to proceed with the ramp. Pressing PB1 terminates the ramp process.

Construction Hints

The total cost of the parts is about $100. I can program the RCM3610 if you do not have the appropriate tools. All I ask is that you send me one along with return postage.

The two PCBs (printed circuit boards) can be purchased from FAR Circuits (**FARcircuits.net**) for $14 for the pair. They do not do plated-through holes, so you will have to insert some jumpers at the appropriate locations. You can find a complete set of PCB files (including the Gerber and drill files) on my website at **www.qsl.net/k3pto**.

There are no critical circuits in this design. I designed the board so that the output of the 25 MHz oscillator has a very short run to the DDS IC. In most cases, the resistor values are not critical. If you want a more exact output level, you may want to calculate better values for R4, R7, and R8 (see the text).

PARTS LIST

This indicates where I purchased the major parts. You can probably find equivalent parts from other vendors and possibly save some money in shipping costs.

LOC	PART NO.	QTY	VENDOR
❑ Circuit Boards		1	Far Circuits
❑ PB1,2,3	26622CK	3	Jameco
❑ Sw1,2	72160CK	2	Jameco
❑ RNET1, RNET2	24643CK	2	Jameco
❑ IC1	RCM3610	1	*Rabbit
❑ Socket for IC1	S7123-ND	1	Digi-Key
❑ IC2 (LCD)	67-1768-ND	1	Digi-Key
❑ IC3 (7805)	51262CK	1	Jameco
❑ IC4 (DDS)	AD9834BRU-ND	1	Digi-Key
❑ IC5 (Osc)	SE1714-ND	1	Digi-Key
❑ IC7 (Op-amp)	AD8529AR-ND	1	Digi-Key
❑ IC8 (Potentiometer)	AD5200BRM10-ND	1	Digi-Key
❑ H1,2,3,4,5	103341CK	2	Jameco
❑ D1	35975CK	1	Jameco
❑ LED1	333877CK	1	Jameco
❑ S1,2,4,5	103157CK	2	Jameco
❑ Pins for S1,2,4,5	100765CK	45	Jameco
❑ S3	S4107-ND	1	Digi-Key
❑ Conn1 (2.5 mm)	202358CK	1	Jameco
❑ Mate for Conn1	190537CK	1	Jameco
❑ Conn2 (RCA)	159484CK	1	Jameco
❑ Mate for Conn2	229921CK	1	Jameco
❑ Box (6x4x2)	270-1806	1	RadioShack

*Rabbit Semiconductor — **www.rabbit.com**

All resistors are 1/4 watt, 5%

❑ R1	100Ω
❑ R2	560Ω
❑ R3	6.8K
❑ R4,R5,R11	200Ω
❑ R7	1K
❑ R8,R9	4.7K
❑ R10	680Ω

All capacitors are monolithic ceramic

❑ C1,C3,C11	0.47 µF
❑ C2,C4,C5,C9	1,000 pf
❑ C6	0.1 µF
❑ C7,C8	0.01 µF
❑ C10	100 pf

Working with SMD ICs can be a challenge, especially the attenuator IC. I strongly recommend that you have a soldering iron with a very small tip and some very thin solder. You should also work using a lamp with a magnifying lens. I have a lamp with a 3X magnifying lens, but sometimes wish it were 5X. When soldering the SMD ICs, the method I use is:

- Tin the pads on the PCB — make sure there are no solder bridges!

- Align the IC on the pads making sure ALL the leads line up.

- Use a strip of plastic electrical tape, cut thin, to fasten it in place.

- Use very thin solder and an iron with a very thin tip to solder it.

- Use solder wick to remove any solder bridges.

You do not have to use the same method of construction as I did with the headers and sockets. I prefer them so that I can easily take apart the system pieces. You can solder wires directly to the PCB instead of using any of the header/socket pairs. If you do use the connectors, you will need to have either a crimp tool for the pins or a pair of small needle-nose pliers to use. I used pliers and did not have any trouble. Both the headers and sockets need to be cut to size. This can be done easily with a utility knife.

I cut the opening for the LCD using a Dremel tool. As it turns out, I cut my opening larger than required because I wanted the LCD to be close to the top surface of the box.

You may need to drill a new mounting hole for the voltage regulator. Some 7805s are different sizes with the hole further from the pins. I did not use a heatsink, but you can if you wish — there is room for a small one.

The crystal oscillator has pin 1 closest to the edge of the board.

Make sure you solder both sides of the components which have PC traces on the top. It helps if you do not mount the leaded components right up against the PCB.

When mounting the sockets, make sure you do NOT mount them right up against the PCB so that you can solder the pins which have connections on the top side.

I soldered 6" wires onto the LED and then soldered the wires to the PCB. This allows you to mount the LED just about anywhere on the cover. Try to drill the mounting hole just large enough for the body of the LED and not so large that it allows the bottom lip to pass through. I usually use Goop to glue LEDs to a plastic lid.

LCD: Note that the schematic shows an extra pin at location 2. The correct wiring for the LCD to the connector is shown in Table 1.

LCD	Connector
1, 5, 7, 8, 9, 10	1 (gnd)
2	3 (+V)
3	No connection (VEE) this can be used for contrast control if desired
4	5 (RS)
6	7 (E)
11	12 (DB4)
12	13 (DB5)
13	14 (DB6)
14	15 (DB7)

■ TABLE 1

I "daisy-chained" the ground connection at the LCD using a long piece of bare wire with sleeving pushed onto it between pins 1 and 5, and 5 and 7.

You may need to drill mounting holes in the PCB, depending on how you choose to mount it in your enclosure. **NV**

SQUARE ROOT ON A PIC
(and Other Small MCUs)

by Noel Henson

Square roots have been in use for thousands of years in construction and astronomy. Today, they are also used for computing RMS values, FFTs, and other types of digital filtering, navigation, and more. With more and more smarts being put into smaller and smaller devices, there is greater need to run a square root function on a small, low-power MCU.

Typical methods for computing square roots are slow and difficult to implement on a small MCU. They require multiply and divide functions. For example, the Newton and Babylonian which are quite popular both require floating-point multiply and divide (see sidebar).

One can implement an integer square root using successive approximation with just a multiply. In this case, a starting root is chosen, usually 1. This value is squared and compared against the number for which the square root is needed. If the squared root is greater, the previous root is the answer. If not, the root is incremented and the process repeats. In other words:

X: number we need the square root of
N: test root

```
X = anything but zero
N = 1
until (N²>X) {
  N = N + 1
  }
N = N - 1
```

It's pretty simple and doesn't need a divide. It does still require a multiply for the n^2 term. How can we get rid of that?

Algorithm Overview

We need to look back to our first-year algebra class. If the square of a number + 1 is needed, $(n+1)^2$, we can expand the equation. Remember this?

$$(n+1)^2 = (n+1)(n+1) = n^2 + 2n + 1$$

What's cool about this is that a variable can be assigned to both n and n^2. Let's call them n and square, respectively. If we assign 1 to both at the beginning of a loop, the multiply for n^2 can be eliminated. For each increment of n, square is incremented by 2n + 1. Upon further examination, the multiply in 2n can be eliminated and replaced with a simple left shift. After that, we only need an increment or addition of 1. Here are the values for the first five squares:

n	square	2n + 1
1	1	3
2	4	5
3	9	7
4	16	9
5	25	11

So you see, for the next value, 6, we simply add 2n + 1, 11, to 25. That results in 36, the square of 6. Now that's simple enough for an MCU.

Eight-bit Implementation Example

Listing 1 is an eight-bit implementation example of this method. Though nearly useless due to its eight-bit input and four-bit result, it will serve to show how the algorithm works on a small PIC; something like a 12F509 or 16F505.

Lines 001 through 006 define the eight-bit variables need. Lines 008 through 011 initialize the n (N) and n^2 (TESTX) variables to 1. It is assumed that the number for which the root is needed has been loaded into X before sqrt is called.

The beggining of the loop that computes the square root starts with 'compute' on line 012. Lines 013, 014 and 015 compare X and and TESTX (n2). If TESTX is

FOR YOUR INFO

More information on the history and computation of square roots can be found on Wikipedia:

en.wikipedia.org/Methods_of_computing_square_roots *and* en.wikipedia.org/Square_root

greater, the branch to 'done' is executed. If not, in lines 018 through 020 ADDEND is used to create 2n+1. A preset on the carry bit is used for the +1 part because it shifts into bit 0 when a rotate (rlf) is executed. There is no shift in a PIC.

Lines 021 and 022 increment TESTX by ADDEND (2n+1) and N are incremented. Line 023 jumps back to compute for the next iteration of the loop. 'done' is branched to when, TESTX is greater than X. Line 025 decrements N by 1 to set it to its previous value; the last one that generates a positive result when TESTX is compared to X. Line 026 simply returns.

32/16-bit Implementation

Listing 2 is a useful square root implementation. It generates a 16-bit square root of a 32-bit unsigned number. This version also works on a small PIC.

Lines 001 through 006 create the needed variables. N is 16 bits. X, TESTX and ADDEND are 32 bits.

Lines 008 through 094 define some macros that will be used to keep the programming of the algorithm simple. clrf16 clears a 16-bit variable. clrf32 clears a 32-bit variable. cmp32 compares two 32-bit variables, non-destructively. copy16 copies a 16-bit variable into a 32-bit variable and clears bits 16-31 of the 32-bit variable. copy32 copies one 32-bit variable into another. rlf32 rotates a 32-bit variable one bit to the left. The carry bit is shifted into bit 0. decf16 decrements a 16-bit variable. incf16 does just the opposite. add32 adds one 32-bit variable into another. sub32 subtracts a 32-bit variable from another.

Lines 096 through 100 initialize the variables N and TESTX. As in the previous example, X must be loaded with the number for which the root is needed.

Lines 102 and 103 compare TESTX to X. If TESTX > X, the branch at line 104 is taken. Lines 105, 106 and 107 create the ADDEND (2N+1). Line 108 adds it to TESTX for the next iteration. Line

LISTING 1: An Eight-bit PIC Example

```
000     ; variables
001             cblock 0x20
002                     N               ; variable for square root
003                     X               ; variable for root
004                     TESTX           ; variable for comparisons to root
005                     ADDEND          ; variable used to modifiy TESTX
006             endc
007
008     sqrt
009             movlw   0x01
010             movwf   N               ; set initial n
011             movwf   TESTX           ; and testx to 1
012     compute
013             movf    TESTX,w         ; compare x and the testx
014             subwf   X,w             ; by subracting the testx from x
015             btfss   STATUS,C        ; skip next if not negative
016             goto    done            ; or branch if it is
017             movf    N,w             ; create the new addend
018             movwf   ADDEND
019             bsf     STATUS,C        ; make the addend = 2n + 1
020             rlf     ADDEND,w
021             addwf   TESTX           ; add it to the testx
022             incf    N               ; increment n for the next test
023             goto    compute         ; and loop
024     done
025             decf    N               ; decrement n to get the last value
026             retlw   0x00            ; we're done so return
```

LISTING 2: A Full 32-bit Routine

```
000     ;variables
001             cblock 0x20
002                     N       : 2
003                     X       : 4
004                     TESTX   : 4
005                     ADDEND  : 4
006             endc
007     macros
008     clrf16  macro   var             ; clear a 16-bit variable
009             clrf    addr            ; clear the LSB
010             clrf    addr+1          ; clear the MSB
011             endm
012
013     clrf32  macro   var             ; clear a 32-bit variable
014             clrf16  addr            ; clear the LSW
015             clrf16  addr+2          ; clear the MSW
016             endm
017
018     cmp32   macro   var1,var2       ; compare 2 32-bit values
019             copy32  val1,TEMPA      ; copy the minuend
020             sub32   TEMPA,VAL2      ; subract the subrahend
021             endm
022
023     copy16  macro   var1,var2       ; perform 16-bit copy to a 32-bit var.
024             movf    var1,w          ; get the LSB of the source
025             movwf   var2            ; copy it to the LSB of the destination
026             movf    var1+1,w        ; get the MSB of the source
027             movwf   var2+1          ; copy it to the MSB of the destination
028             clrf    var2+2          ; clear the MSW of the destination
029             clrf    var2+3
030             endm
031
032     copy32  macro   var1,var2       ; copy a 32-bit variable
033             movf    var1,w          ; get the LSB of the source
034             movwf   var2            ; copy it to the LSB of the destination
035             movf    var1+1,w        ; get the CLSB of the source
036             movwf   var2+           ; copy to the CLSB of the destination1
037             movf    var1+2,w        ; get the CMSB of the source
038             movwf   var2+           ; copy to the CMSB of the destination2
039             movf    var1+3,w        ; get the MSB of the source
040             movwf   var2+           ; copy to the MSB of the destination3
041             endm
042
```

continued ...

Listing 2 continued ...

```
043     rlf32   macro   var             ; perform a rotate on a 32-bit variable
044             rlf     var             ; shift-up LSB
045             rlf var+1               ; shift-up CLSB
046             rlf     var+2           ; shift-up CMSB
047             rlf     var+3           ; shift-up MSB
048             endm
049
050     decf16  macro   var             ; decrement a 16-bit variable
051             decf    var             ; decrement the LSB
052             btfss   STATUS,C        ; if underflow,
053             decf    var+1           ; optionally decrement the MSB
054             endm
055
056     incf16  macro   var             ; increment a 16-bit variable
057             incf    var             ; increment the LSB
058             btfsc   STATUS,C        ; if overflow,
059             incf    var+1           ; optionally increment the MSB
060             endm
061
062     add32   macro   var1,var2       ; add two 32-bit variables
063             movf    var2,w          ; get the LSB of the addend
064             addwf   var1            ; and add it
065             btfsc   STATUS,C        ; if carry,
066             incf    var1+1          ; increment the CLSB
067             movf    var2+1,w        ; get the CLSB of the addend
068             addwf   var1+1          ; and add it
069             btfsc   STATUS,C        ; if carry,
070             incf    var1+2          ; increment the CMSB
071             movf    var2+2,w        ; get the CMSB of the addend
072             addwf   var1+2          ; and add it
073             btfsc   STATUS,C        ; if carry,
074             incf    var1+3          ; increment the MSB
075             movf    var2+3,w        ; get the MSB of the addend
076             addwf   var1+3          ; and add it
077             endm
078
079     sub32   macro   var1,var2       ; two 32-bit variables
080             movf    var2,w          ; get the LSB of the subtrahend
081             subwf   var1            ; and subtract it
082             btfss   STATUS,C        ; if borrow,
083             decf    var1+1          ; decrement the CLSB
084             movf    var2+1,w        ; get the CLSB of the subtrahend
085             subwf   var1+1          ; and subtract it
086             btfss   STATUS,C        ; if borrow,
087             decf    var1+2          ; decrement the CMSB
088             movf    var2+2,w        ; get the CMSB of the subtrahend
089             subwf   var1+2          ; and subtract it
090             btfss   STATUS,C        ; if borrow,
091             decf    var1+3          ; decrement the MSB
092             movf    var2+3,w        ; get the MSB of the subtrahend
093             subwf   var1+3          ; and subtract it
094             endm
095     sqrt
096             clrf16  N               ; set initial n and testx to 1
097             clrf32  TESTX
098             movlw   0x01
099             movwf   N
100             movwf   TESTX
101     compute
102             cmp32   TESTX,X         ; compare the testx to x
103             btfss   STATUS,C        ; if positive (x<testx) skip the branch
104             goto    done            ; branch to done
105             copy16  N,ADDEND        ; make addend = 2n+1
106             bsf     STATUS,C        ; preset the carry (the +1 part)
107             rlf32   ADDEND,w        ; shift up the addend (the 2n part)
108             add32   TESTX,ADDEND    ; add it to the testx
109             incf16  N               ; increment n
110             goto    compute         ; loop back to try again
111     done
112             decf16  N               ; decrement n
113             retlw   0x00            ; and return
```

109 increments N. Line 110 branches back to the start of the 'compute' loop.

When TESTX is greater than X, 'done' is branched to. As before, N is decremented. Line 113 returns.

Optimizations

Pretty simple, isn't it? But it does have some performance issues. If we assume a completely random set of 32-bit input values, the average number of 'compute' iterations to find a square root is 32,768. If the range of input values is lower in a particular application, the average number of iterations will be lower. But what can be done to increase the performance?

One thing is to range the input value. Ranging determines the magnitude of the input value. It uses the magnitude to set N and TESTX to values much closer to that of the input thus reducing the number of iterations needed to converge on a result. A ranging table with 16 entries would cut the average number of iterations to 1/16. A table with 32 entries would cut the average to 1/32 or 1024. The downside of a larger table is that is uses more of a very limited resource: program memory.

An example of a 16-entry ranging solution is shown in Listing 3. Lines 001 through 016 form a simple macro that compares the square of a provided value to X. If X is greater, a branch to 'compute' in Listing 2 is performed. If X is not greater, the macro 'falls through' the end of the routine to the next MCU instruction. Lines 20 through 36 form the ranging table. The values shown are for an even distribution of the ranges. These values can be tweaked to focus on the ranges of expected input values of a particular application.

Performance Analysis

So how fast is it? Well, assuming we are not using the optimization in Listing 3 and a 20 MHz PIC, let's figure it out. A 20 MHz PIC has

an instruction execution time of 200ns. Now all that has to be done is add up the number of instructions in the setup, the compute loop and the exit.

The setup, just after 'sqrt,' includes these instructions:

- 2 clrf16 (macro of 2 instructions)
- 4 clrf32 (macro of 4 instructions)
- 1 movlw
- 2 movwf (twice)
- 2 implied call

—
- 11 instructions * 200 nS = 2.2 uS

The compute loop is comprised of:

- 22 cmp32 (macro of 22 instructions)
- 6 copy16 (macro of 6 instructions)
- 4 rlf32 (macro of 4 instructions)
- 14 add32 (macro of 16 instructions)
- 3 incf16 (macro of 3 instructions)
- 2 btfss (but only 1 if the branch is taken to done)
- 2 goto (the 'goto done' is ignored)
- 1 bsf

—
- 53 instructions * 200 nS = 10.6 uS

Finishing up is just these:

- 3 decf16 (macro of 3 instructions)
- 2 retlw

—
- 5 instructions * 200 nS = 1 uS

Armed with this information, we can compute some timing values. These are rough and don't account for the exiting of the compute loop in the middle on the final iteration (TESTX>X). The best case timing would be the square root of 1. This would cause one complete execution of the loop (10.6 uS) plus the entry/setup and times of 2.2 uS and 1 uS. Yielding 13.8 uS, approximately. A worst-case value would be the square root of 2^32-1 or 0xFFFFFFFF. That would mean 65535 iterations of the computer loop or 695 mS plus the entry and exit times. The average time would be half that or 348 mS.

If the optimzation of Listing 3 is used, this average time would be cut down to about 22 mS. Again, if the range of your inputs is limited the ranging table can be optimized even further for more performance gain. If the input ranges are always less than 2^{24} the routine can be modified to produce a 12-bit result from a 24-bit input. Faster eight-bit MCUs like those from Cygnal run at 25MIPs. These also have a few more instructions which will further decrease the execution time. From these one can expect an average execution time of around 4 mS.

Scaling and Fractional Square Roots

But what if you need two decimal digits of precision? What good is this integer square root function you ask? Quite a bit actually. Using fixed-point scaling fractional results can be obtained. The advantage of fixed-point functions as opposed to floating-point functions is speed. They're usually faster even than using an FPU.

To demonstrate, let's compute the square root of 10 to two decimal places using integer (fixed-point) math. Here is an interesting list of square roots:

10	3.1623
100	10
1,000	31.623
10,000	100
100,000	316.23
1,000,000	1,000

TERMS

- ***LSB*** — least significant byte, byte 0, bits 0-7
- ***CLSB*** — center-least significant byte, byte 1, bits 8-15
- ***CMSB*** — center-most significant byte, byte 2, bits 16-23
- ***MSB*** — most significant byte, byte 3, bits 24-31

LISTING 3: Optimization Using Ranging

```
macros
range   macro myn
        movlw   myn & 0xff              ; load the LSB of myn into N
        movwf   N
        movlw   myn >> 8                ; load the MSB of myn into N
        movwf   N+1
        movlw   (myn*myn) & 0xff        ; load the LSB of myn^2 into
        movwf   TESTX                   ; TESTX
        movlw   ((myn*myn) >> 8) & 0xff ; load the CLSB of myn^2 into
        movwf   TESTX+1                 ; TESTX
        movlw   ((myn*myn) >> 16) & 0xff ; load the CMSB of myn^2 into
        movwf   TESTX+2                 ; TESTX
        movlw   (myn*myn) >> 24         ; load the MSB of myn^2 into
        movwf   TESTX+3                 ; TESTX
        cmp32   TEXTX,X                 ; compare TESTX to X
        btfss   STATUS,C                ; if less, finish computation
        goto    compute                 ; with this branch
                                        ; or fall through to next test
endm

sqrt
        range   0xF000                  ; test for each range
        range   0xE000                  ; if X is greater,
        range   0xD000                  ; branch to compute
        range   0xC000
        range   0xB000
        range   0xA000
        range   0x9000
        range   0x8000
        range   0x7000
        range   0x6000
        range   0x5000
        range   0x4000
        range   0x3000
        range   0x2000
        range   0x1000
        range   0x0001
        goto    error                   ; something is wrong, error out
```

This shows that every time the base number, 10, is multiplied by 100, an extra digit of precision is available before the decimal point. If one decimal digit of precision is needed, the initial number must be multiplied by 100. If two are needed, 10000 must be the multiplier. So, for every digit of precision needed, just multiply by 100 before the square root is computed. It is essentially a two-digit, decimal left shift.

Using the square root function presented here and the small MCU being used, it is not practical to multiply an input number by 100 for each decimal digit. But if we switch our thinking from decimal to binary, we can still gain the desired accuracy.

If the number is shifted up by two bits, we gain one bit of fraction. In decimal this bit represents 0.0 and 0.5. If we shift up by four bits, two fractional bits are gained. These represent 0.00, 0.25, 0.50 and 0.75. And so on. So a shift up by 14 bits will give seven fractional bits giving a fractional resolution of 1/128. This is even better than the 1/100 given by shifting up by two decimal digits. Again all needs for a multiply have been avoided. This does limit the maximum input number to 18 bits. If less precision is needed, say four bits, the maximum would be 24 bits.

Conclusion

Often small MCUs are underestimated in the amount of real math they can perform. Given a good understanding of the constraints of the intended use and a good grip of math, they can perform astonishing feats; including integer and fractional square roots with out using a single multiply or divide. **NV**

Noel Henson has been designing and programming embedded systems for over 20 years. He has developed everything from simple remote controls to custom supercomputers. He currently owns Lane Mountain Logic, an embedded design and programming firm.

METHODS

Babylonian Method:

$X_{n+1} = (X_n + r/X_n)/2$

- Start X with any value, the closer to the square root the better.
- Continue to replace X with the average of X and r/X until X converges on the square root with the desired precision.

Newton's Method:

$X_{n+1} = X_n - (f(x_n)/f'(x_n))$

where

$f(x) = X^2 - r$

$f'(x) = 2X$

- As above, start X with any value, the closer to the square root the better.
- Continue to iterate the formula until X converges on the square root with the desired precision.

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"CREATE THE FUTURE" CALL FOR ENTRIES

Emhart Teknologies invites you for the fifth annual "Create the Future" Design Contest, featuring a top prize of $20,000 or a 2007 hybrid car. Visit **www.emhartcontest.com** for the details. There is no cost to enter.

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- Medical
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Entries must be received by November 17, 2006. Visit **www.emhartcontest.com** for the rules and official entry form. **NV**

ELECTRONET

>>>> go to www.nutsvolts.com — click Electro-Net <<<<

TECH FORUM

This is a READER-TO-READER Column.

All questions *AND* answers are submitted by *Nuts & Volts* readers and are intended to promote the exchange of ideas and provide assistance for solving problems of a technical nature. Questions are subject to editing and will be published on a space available basis if deemed suitable by the publisher. Answers are submitted by readers and NO GUARANTEES WHATSOEVER are made by the publisher. The implementation of any answer printed in this column may require varying degrees of technical experience and should only be attempted by qualified individuals. Always use common sense and good judgement!

>>> QUESTIONS

I need to build a timer that will let my tube amp warm up first and then connect the HV to the tube. I need a delay of 30 sec. Any schematic for the 555 or 4011?

#11061 **Richard Bitan**
via email

I have been an avid reader of both *Nuts and Volts* and now *SERVO* for quite some time. I have several types of robots and am currently working on my masterpiece. This one uses a PC/104 main computer talking to various Atmel controllers.

I am trying to find either the software, or the tools to create a program that will allow me to send control and status signals via the Internet from any remote browser to the robot. Once the control signals are received by the bot, I would then need to be able to use these in my control software.

Status signals would then be sent in the reverse direction back to the browser. I'm currently using Visual Basic as the master control software.

Continued on Page 110

All questions and answers should be sent by email to forum@nutsvolts.com All *diagrams should be computer generated and sent with your submission as an attachment.*

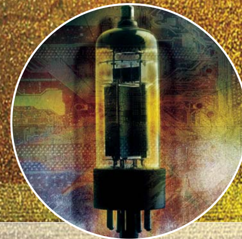
QUESTIONS
To be considered, all questions should relate to one or more of the following:

1. Circuit Design
2. Electronic Theory
3. Problem Solving
4. Other Similar Topics

- Be brief but include all pertinent information. If no one knows what you're asking, you won't get any response (and we probably won't print it either).
- Include your Name, Address, Phone Number, and email. Only your Name, City, and State will be published with the question, but we may need to contact you.
- No questions will be accepted that offer equipment for sale or equipment wanted to buy.
- Selected questions will be printed once on a space available basis.
- Questions are subject to editing.

ANSWERS

- Include in the subject line of your email, the question number that appears directly below the question you are responding to.
- Payment of $25.00 will be sent if your answer is printed. Be sure to include your mailing address or we cannot send payment.
- Only your Name, City, and State, will be printed, unless you say otherwise. If you want your email address included, indicate to that effect.
- Comments regarding answers printed in this column may be printed in the Reader Feedback section if space allows.



by Vaughn D. Martin

The Triode is 100 Years Old This Year

This year marks the 100th anniversary of Lee de Forest's Audion or first vacuum tube triode (Figure 1). This was the most famous of de Forest's 180 patented inventions. This vast improvement upon John Ambrose Fleming's valve changed the world like few other events since.

The "valve" was a vacuum tube diode that Fleming invented as a modification to an Edison light bulb by adding a second element to it. Lee de Forest's triode or "Audion" as he called it ushered in the age of radio and electronic communications. The Audion detected radio signals, and then it could amplify them to produce audio. Finally, it served as the basis of an oscillator for the final transmission of signals.

This era of early radio was one in which only a few visionaries and promoters realized its great potential, and this fostered ferocious competition and frequent legal battles.

de Forest's Impact

The significance of de Forest's invention was at least two-fold. First, it allowed control over the stream of electrons between the tube's cathode and anode, which is the basis of electronic communications, as just explained. Secondly though, this invention inspired and planted the seed for further improvements to a whole bevy of vacuum tubes and related devices, including the cathode ray tube, X-ray tube, photomultiplier tube, and klystron. The following site shows a chronological timeline of inventions relating to vacuum tubes, and later television **http://inventors.about.com/library/inventors/bl_television_timeline.htm**.

How it All Began

The earliest crude forms of the vacuum tubes appeared in the late 17th century. However insufficient technology, including efficient vacuum pumps, advanced glassblowing techniques, and the Ruhmkorff induction coil prevented them from being more than a "laboratory curiosity." Incidentally, this coil standing alone could produce sparks more than one foot in length. The first radio transmitters used such a coil (see Figure 2).

One Inventor Inspired by the Audion

Lee de Forest inspired inventors, like Irving Langmuir, to produce spin-offs of the triode vacuum tube. Langmuir was a physicist and chemist who promoted a better understanding of plasmas, heat transfer, and thermionic phenomena. This allowed Langmuir to invent a high-vacuum electron tube and gas-filled incandescent lamps. Langmuir invented the first high performance practical gas-filled bulbs.

A common myth is that Edison invented the light bulb. Edison just improved upon a 50-year-old idea. In 1879, Edison used a small carbonized filament in a vacuum inside a glass enclosure or envelope to produce a more reliable light source. But Langmuir, a name most people have never heard of, really invented a far more useful, optically-efficient device.

One account of the significance of this discovery attributed to it was a savings in America's lighting bill of $1,000,000 a night. This was especially welcome since it occurred in the middle of the Great Depression.

Lee de Forest's Illustrious Life

After graduating with a Ph.D. from Yale, de Forest had numerous jobs related to his education and interest in electronics. He preferred to be his own man, however, and never worked with any one company very long before striking out on his own. His interest in yet-to-be-invented

FIGURE 2. The Ruhmkorff induction coil, an integral part of early attempts to make a vacuum tube.

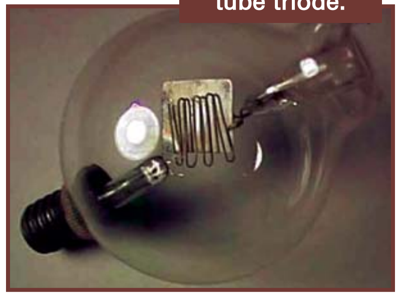


FIGURE 1. A photo of de Forest's Audion, the first vacuum tube triode.

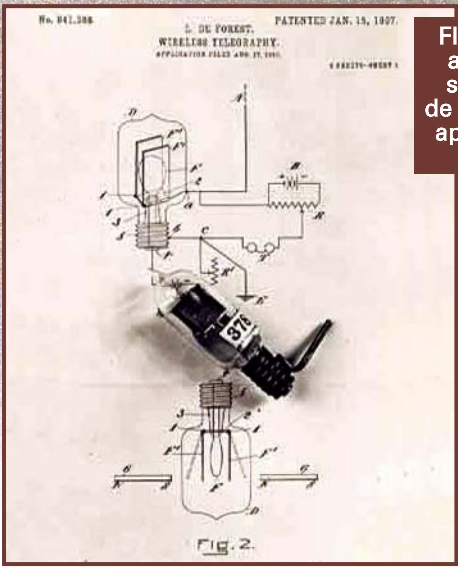


FIGURE 3. The actual sketch submitted by de Forest (patent application) for his Audion.

scientific devices was a tough sell in the business world, though, since his "products" did not yet exist.

Lee was a personable man who appreciated the performing arts, especially opera. In fact, newspaper accounts tell of him sending the voices of opera singers to members of the press stationed at receiving sets as a way to promote the medium of radio, which was still in its infancy.

de Forest also fostered amateur radio by making broadcasts that many hams would receive. One broadcast of historical merit was his coverage of the Hughes-Wilson Presidential election returns in 1916. This actually preceded what many believe was the first radio broadcast in 1920 by KDKA in Pittsburgh. Interestingly, de Forest became very vocal in the 1950s, over his remorse over what radio had become since he referred to himself as the father of radio. He felt radio was only comprised of second rate jazz, sickening crooners, and constant interruptions for "sales talk" — as he called commercials.

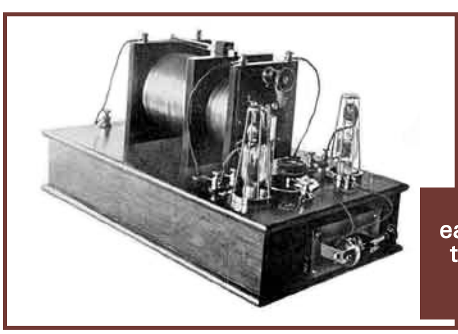


FIGURE 4. An early Lee de Forest transmitter using his Oscillion vacuum tubes.

de Forest briefly worked for the Federal Telegraph Company in Palo Alto, CA while he was perfecting and promoting his Audion vacuum tube as an amplifier (Figure 3). The telephone company used it in transcontinental phone calls, but it was cost-prohibitive for the average person. It would cost over a week's pay (at the time) for just a few minutes. de Forest received $50,000 for this invention.

de Forest's Love of the Performing Arts

By his own admission, de Forest spent the happiest 30 years of his life in Hollywood, where he died at the age of 88. Appropriately so, because de Forest's second most notable invention was adding sound to motion pictures. He called this invention the "Phonofilm." It added a synchronized sound overlay to film. This significant feat earned him an Oscar from the Motion Picture Arts and Sciences foundation in 1959 for this 1920 invention. However, the Phonofilm was not the system used in the famous talkie movie *The Jazz Singer*.

The de Forest process used a device called a light valve to expose a series of dark and light patches right on the film's sprocket edge. A photocell read these areas and converted them to sound with a great success of being in synch with the picture.

Dispelling Another Common Myth

By 1916, the Audion was the basis of an oscillator for the radiotelephone transmitter for experimental broadcasts in New York City. By now, de Forest's Audion vacuum tubes had emerged into two large Oscillion vacuum tubes that he used as generators of RF (radio frequency) current. Figure 4 shows one of de Forest's earliest radio transmitters made with Oscillion vacuum tubes.

The early radiotelephone transmitters before 1916 were not based on de Forest's Audion vacuum tubes. Virtually all early broadcasters of voice and music used some version of the Poulsen DC arc. Generating high frequency signals in radio's infancy assumed a number of innovative forms.

Heinrich Hertz is generally accepted and credited with being the first to accomplish this, but in a crude form. He used a spark-excited resonant circuit. This might have been useful in telegraphy, but since it only generated damped waves that would quickly dissipate, it was not useful in any sort of applications related to modulation schemes. In 1900, William Duddell succeeded in creating high frequency undamped signals that he called the "singing arcs."

Duddell accomplished this with an arc light as the power source to continuously excite and, in turn, cause oscillations in a tank or parallel-tuned resonant circuit. But it was Valdemar Poulsen in 1906 who invented the first practical arc transmitter for transmission work. Poulsen may be best known for inventing the first magnetic recording that he demonstrated in principle around 1898 in what he called his "telegraphone," which was actually a magnetic wire recording. This was the precursor of tape recording.

Strife and Toil

de Forest's life was not without controversy, as four wives and expensive litigation attests to that. His first marriage lasted less than a year, then a year later he married a liberated electrical engineer who was not at all content living in his shadow. His third wife was a singer, Mary Mayo, and 18 years later he married his last wife, Maria Mosquini, an actress. She was his favorite by his own account, and they spent his last and happiest years in Hollywood.

de Forest was frequently accused of unethical business practices. In 1903, when visiting fellow inventor Reginald Fessenden's lab, he observed Fessenden's Liquid Barretter detector and purportedly stole the idea. After three bruising trials, Fessenden finally prevailed and received an injunction against de

Forest for patent infringement.

In 1902, de Forest aligned himself with Abraham White (a Wall Street promoter) and they formed De Forest Wireless Telegraph Company. They approached the War Department and the US Navy, and had a public stock offering. Unfortunately, the actual value of the radio equipment sold did not match the hype of the promoter. Discredited, de Forest went on trial with two other promoters who were found guilty of misleading the public in the stock offering. However, de Forest was acquitted.

de Forest did realize one early victory in 1904 by successfully demonstrating a wireless telegraph station to the US Navy in San Juan, Puerto Rico. This was with a valve (diode vacuum tube), since he had not yet invented his triode.

The Navy Success Story

In 1909, de Forest eventually sold his arc radiotelephone systems to the Navy. To test them, he played a record on a wind-up phonograph. Much to his pleasure and surprise, wireless ham radio operators intercepted his test signals. After successfully completing the test phase, de Forest equipped the Navy fleet's lead ship, the U.S.S. Ohio, with one of his arc transmitters and a wind-up phonograph. During an around-the-world duty cruise between 1907 and 1908, de Forest accompanied his equipment aboard the U.S.S. Ohio and successfully communicated with Mare Island on the other coast during June of 1908.

A Bitter-Sweet Ending

There were many ups and downs for de Forest, but his most famous legal battle was when he and Edwin Armstrong both simultaneously claimed they invented the regenerative or negative feedback principle of the Audion. This allowed feeding back weak signals at the tube's output to its input to strengthen the signals.

This litigation lasted 20 years from 1914 to 1934, and through it all, Armstrong won the hearts of the technical community. Somewhat disgraced, de Forest's peers no longer took him seriously as an inventor. de Forest had to sell his prized palatial estate on the Hudson River that he called Riverlure to pay for legal expenses during his long battle with Armstrong and others. It was at this stage of his life that he decided to live out his days in Hollywood. **NV**

by H. Ward Silver

Making Something From Nothing

In the beginning there was only noise, but humans have learned to make their own electromagnetic crackles and pops with a device that is as much as possible ... empty! Radio and vacuum tubes grew up together from their genesis a century ago, but their history was not a clean, step-by-step process. Theory and experiment took turns leapfrogging each other, mixing sudden discoveries and steady refinements. Their story begins in the Age of Steam.

The Dawn of Radio

The story of radio really begins in 1830, when Joseph Henry (for whom the unit of inductance is named and who is shown in Figure 1) observed that energy could be conducted from one coil to another by *mutual inductance*. Michael Faraday (whose name is borne by the unit of capacitance, the farad) observed it a year later. This discovery was one of many in electricity and magnetism, culminating in James Clerk Maxwell's 1865 paper describing electromagnetism mathematically.

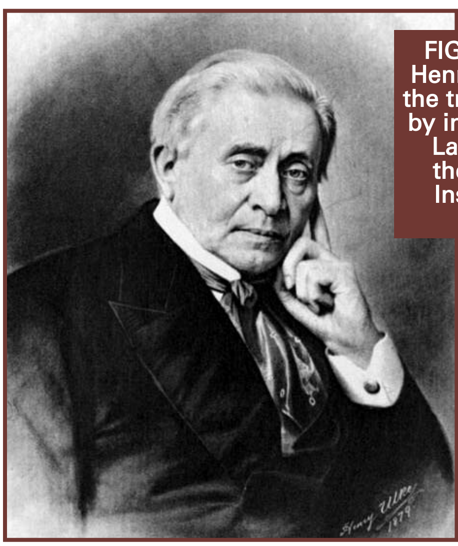


FIGURE 1. Joseph Henry first observed the transfer of energy by induction in 1830. Later he became the Smithsonian Institution's first director.

Later in 1881, Oliver Heaviside simplified that description into the form known today as "Maxwell's Equations." (Heaviside is also credited as being the first to speculate that a charged layer above the Earth (now known as the *ionosphere*) is responsible for the long-distance propagation of radio waves.)

Also in 1865, the first system capable of sending messages without wires was demonstrated by Virginia dentist Mahlon Loomis. While he received a patent for his system in 1872, Loomis did not understand how it worked and was not able to make commercial use of it.

In the mid-1880s, development of what we would now consider "real radio" began in earnest. While experimenting with nerve impulses in 1885, Edouard Branly invented the *coherer* — a tube filled with fine metal filings sketched in Figure 2 — to detect faint electrical signals. The filings "cohere" or move closer together in the presence of an electric field (such as a radio signal), lowering the resistance through them. In 1894, the coherer was refined by Oliver Lodge, whose *tikker* converted the changes in resistance to audible clicks.

FIGURE 2. The coherer is basically a tube containing iron filings between two electrodes. Electromagnetic fields cause the resistance through the filings to decrease.

At the same time, physicist Heinrich Hertz was making significant theoretical strides in the understanding of radio waves. He transmitted signals across his lab in 1887 as UHF radio waves. In the same year, Michelson and Morley published the results of their experiment showing electromagnetic energy (in the form of light) travels without requiring an all-pervading "aether."

While experimenting with light bulb filaments in 1883, American inventor Thomas Edison observed that electric charge would travel from a heated metal surface towards a more positively-charged electrode. He patented the *Edison Effect* (based on *thermionic emission*), but was focused on developing electric lighting and it fell to Ambrose Fleming to apply it.

Fleming worked with thermionic emisson for a number of years, discovering that the uni-directional current flow between the two electrodes could be used to sense (or *detect*) radio waves. (During this period, J.J. Thompson determined that the electric charges were components of atoms, which were named *electrons*.) In 1904, Fleming received a patent for a two-electrode tube, known as a *diode*. At best, however, the diodes and coherers could merely convert signals from one form to another (such as waves to clicks) and could not increase their strength. This greatly limited

the range of early wireless systems.

Amplification became possible when Lee de Forest discovered that placement of a charged wire between the diode's two electrodes affected the flow of current between them. His early Audion tubes (see Figure 3) had just a single wire for control, but it was soon determined that a mesh or *grid* of wires improved the tube's detection sensitivity. Patented by de Forest in 1906, the three-electrode tube, or *triode*, could use a small grid voltage to control the much larger currents that flowed from the heated electrode (the *cathode*) to the collecting electrode (the *plate*), effectively amplifying the small input signal. With the Audion's ability to amplify as well as detect, the modern era of radio and electronics had arrived.

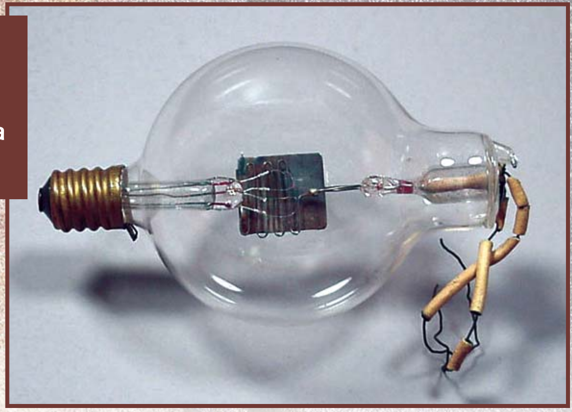


FIGURE 3. The Audion was the first device capable of amplifying a signal and had three elements: a filament (cathode), a control grid, and a plate. Photo courtesy of Mike Schultz, www.uv201.com.

Turning on Radio

In 1894, the experiments of Hertz and others attracted the attention of a young Italian by the name of Guglielmo Marconi. He became fascinated with the idea of sending messages without wires and began a series of experiments based on what he'd read in the 19th-century equivalents of *Nuts & Volts*. Working in the village of Salvan, Italy, the range of his wireless messages increased slowly until the transmitter and receiver were completely out of sight of each other. Remember that wireless technology was exotic stuff in Victorian times, much as molecular biology is today!

After seven years of development, in 1901, as the Wright brothers were building their first airplanes, Marconi set up a receiver on Signal Hill in Newfoundland, Canada. On December 12th, he was able to receive a single letter, "S," transmitted from Cornwall, England and the radio race was on. Although others such as Tesla also demonstrated wireless transmission, Marconi was the first to successfully commercialize his inventions and so he is known as the "father of radio."

Cutting-edge radio technology of the day was Morse-based, of course. Because there were no sources of steady radio-frequency (RF) signals, an arc was used. As you can hear on an AM broadcast receiver, an arc such as a lightning bolt contains energy on a wide range of frequencies — from DC through light! Marconi's transmitters generated powerful arcs whose RF energy was extracted and radiated by antennas tuned to frequencies below 100 kHz. A *rotary spark* station of yore generated many kilowatts of power — not only strong RF signals, but deafening roars and crashes of sound, too!

There were numerous other engineers and experimenters improving radio technology. Two of the best-known are Reginald Fessenden and Valdemar Poulsen. Spark transmitters were extremely inefficient and spread what RF they did generate across the radio spectrum. Poulsen reduced the transmitted signal's bandwidth by connecting a tuned circuit across the arc. This allowed many more stations to share the airwaves and improved reception distances dramatically.

A former assistant of Edison, Fessenden's most significant contribution of many was to construct *continuous-wave* (CW) transmitters that operated on a single frequency. Figure 4 shows the dramatic improvements in efficiency achieved by changing from spark signals to CW. The RF was generated by high-frequency alternators designed by General Electric engineer E.F.W. Alexanderson. Operating at about 50 kHz, alternator-based transmitters were quite an improvement and soon most stations were using them at frequencies from 15 to 60 kHz. Fessenden used one to make the world's first broadcast of speech and music on Christmas Eve, 1906.

The airwaves were not limited to commercial and military stations. As radio became widespread, so did experimentation by private individuals, some of whom formed the Radio Club of America in 1907. It is estimated that by 1910 there were as many as 10,000 wireless enthusiasts building transmitters and receivers! Encouraged and

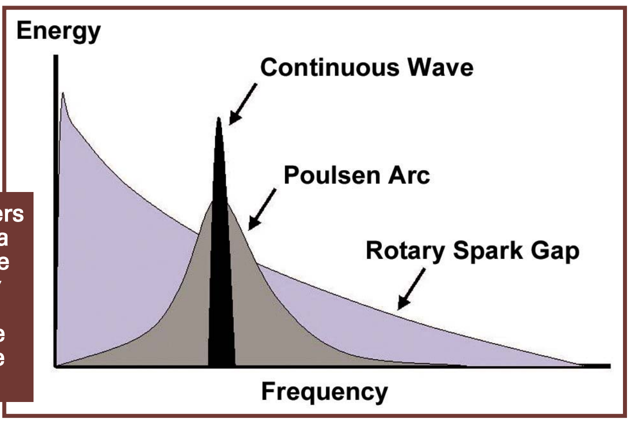


FIGURE 4. Spark transmitters transmitted energy over a very wide bandwidth. The Poulsen arc dramatically reduced wasted signal power. Continuous Wave (CW) transmitters are the most efficient of all.

VACUUM TUBE TERMINOLOGY

■ *Cathode* — The element from which electrons are generated.

■ *Control grid* — A grid designed to perform amplification.

■ *Element* — One of the tube's electrodes that performs an electrical function.

■ *Envelope* — A tube's outer shell.

■ *Filament* or *Heater* — The element that heats the cathode.

■ *Gassy* — A tube whose vacuum has been contaminated by gas.

■ *Getter* — An electrode that absorbs gas molecules to preserve the tube's vacuum.

■ *Grid* — An element that acts to control electron flow from cathode to plate.

■ *Octal* — A tube with eight pins.

■ *Pins* — The external connections to a tube's elements.

■ *Plate* — The element at which electron flow terminates.

■ *Screen grid* — A grid designed to perform protective or isolation functions.

■ *Valve* — The English term for a tube.

informed by magazines such as Hugo Gernsback's *Modern Electrics*, several hundred thousand citizens were engaged in some form of radio experimentation by the start of World War I. Licensing of these amateurs or "hams" began in 1912 and the American Radio Relay League was formed in 1914. Both the RCofA and ARRL are still in existence today!

Broadcasting and Riding the Short-Waves

Radio captivated the public interest in the early 1900s much as the Internet did a century later. Broadcasting got its start in 1909 as Charles Herrold began transmitting from his technical school in San Jose, CA. After the war ended, interest in receiving broadcasts soared. KDKA in Pittsburgh, PA received the first broadcasting license in 1920 and Herrold's station became KCBS the following year.

Early broadcasters used new *amplitude modulation* (AM) technology, allowing them to provide speech and music to the listening public. AM broadcasting was made possible by the new and powerful vacuum tubes developed for the military during the war. These tubes could develop powerful signals of hundreds (!) of watts on the *long-wave* bands between 545 and 220 meter wavelengths (1,350 to 550 kHz). By 1923, broadcast programs were heard every evening throughout the United States.

Before 1920, most radio engineers were convinced that the longer the wavelength of the radio wave (or the lower its frequency), the greater its range. Thus, the most important radio services — military, commercial, and broadcasting — preferred radio wavelengths of hundreds of meters. In 1923, the first "frequency bands" were created, relegating amateurs to the "worthless" bands with meager wavelengths of 200 meters or less (1.5 MHz or higher).

This turned out to be good for the amateurs or "hams." They rapidly discovered that the *short-waves* supported communication over extremely long distances. (The secret turned out to be signal reflections from the ionosphere and ground.) In November of 1923, amateurs made the first two-way, short-wave transmissions across the Atlantic between 1BCG (a station in Massachusetts sponsored by the Radio Club of America) and Leon Deloy, F8AB in France. Distance records fell rapidly with the only frequency limits being those of vacuum tube technology. New tubes and receivers were vastly more sensitive than before, allowing communications around the world with powers of a few watts.

Soon, the services that had clamored for long-wave assignments were demanding short-wave spectrum from the new Federal Radio Commission. The late 1920s were a tumultuous time of rapidly advancing technology as radio permeated every aspect of modern life. Nations found themselves in competition for spectrum access as signals routinely ignored national boundaries. This grand awakening culminated in the formation of the International Telecommunications Union in 1934 and created modern radio spectrum

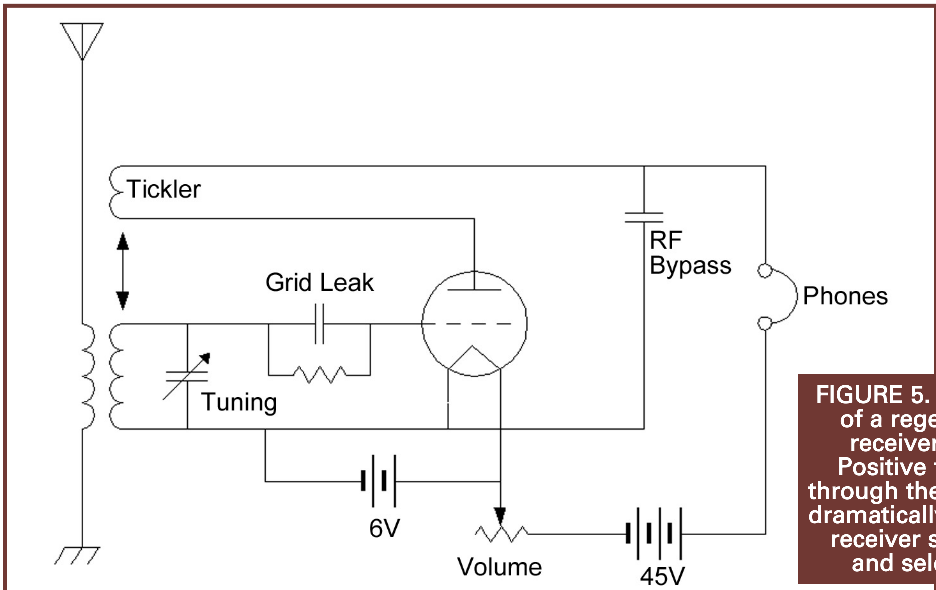


FIGURE 5. The circuit of a regenerative receiver circuit. Positive feedback through the tickler coil dramatically increased receiver sensitivity and selectivity.

management. At home, the Communications Act of 1934 created the Federal Communications Commission (FCC) which administers all telecommunications activity in the US.

Edwin Armstrong

No discussion of early radio would be complete without the inventions of Major Edwin H. Armstrong. With the possible exception of Marconi, no other individual had such a large impact on the development of radio in so many areas.

Armstrong was responsible for three major advances in the radio arts (and many smaller ones). The first was the *regenerative receiver* patented in 1914 by Armstrong while a junior in college. The "regen" was the first electronic circuit to use feedback in order to increase *sensitivity* (the ability to receive weak signals) and *selectivity* (the ability to distinguish between signals). Figure 5 shows the schematic of a regenerative receiver. By allowing the receiver to operate at the edge of oscillation, even extremely weak Morse signals could be detected.

His patent of 1918 was even more important. The *superheterodyne* receiver converts signals from one frequency to another by *mixing* them with another frequency and then selecting from the sum and difference frequencies (*heterodynes*) that result. The superheterodyne can receive a wide range of frequencies by converting them to a single frequency (the *intermediate frequency* or IF stage) where high-gain amplifiers and filters can be employed. The "superhet" design is the basis of nearly all radios in use today, nearly 90 years later!

Third was the development of wide-bandwidth *frequency modulation* (FM) transmission and reception in 1935. Armstrong had learned that nearly all static and noise is amplitude-modulated. Attempting to remove noise from an AM signal would also destroy the desired signal. His solution was to change the method of signal modulation from AM to FM and to increase the bandwidth of the FM signal for good fidelity. He succeeded spectacularly as fans of FM radio know. FM signals are the most common in the world, with the exception of mobile phone transmissions. Armstrong also invented *multiplexed FM*, the technology used for stereo transmission.

100 Years Down the Tube

So much from something so empty! The vacuum tube's story is also the story of the beginning of the Industrial Age. Just as steam power extended our physical abilities, radio and electronics enabled us to extend our communications abilities. While the transistor and IC are the electronic "second stage," the vacuum tube was indubitably the rocket that lifted us off the launching pad. **NV**

FURTHER READING

■ Early Broadcast Radio History — **earlyradiohistory.us**

■ *200 Meters and Down* by Clinton B. DeSoto, published by the ARRL (**www.arrl.org**) — A history of amateur radio until the late 1920s.

■ Wikipedia — **www.wikipedia.org** — Many excellent entries on radio-related topics.

■ Jurassic Radio — **www.oldradio.com/archives/jurassic** — Detailed stories on early radio technology.

■ *Empire of the Air: The Men Who Made Radio* by Tom Lewis — The lives and battles of Lee de Forest, Edwin Armstrong, and David Sarnoff.

■ Edwin Armstrong — **users.erols.com/oldradio** — Detailed information on Edwin Armstrong's experiences and his contributions to radio.

■ ARRL — **www.arrl.org** — The National Association for Amateur Radio.

■ Radio Club of America — **www.radioclubofamerica.org** — The world's oldest radio organization.

by Edward Driscoll, Jr.

David Sarnoff and The Birth of AM Radio

In March of 1998, *Time Magazine* named David Sarnoff to its "Time 100" list of the most influential people of the 20th century:

It is nearly impossible to imagine that it was less than 60 years ago, in 1939, when David Sarnoff told a crowd of curious viewers, "Now we add sight to sound." Sarnoff went on to say, "It is with a feeling of humbleness that I come to this moment of announcing the birth in this country of a new art so important in its implications that it is bound to affect all society. It is an art which shines like a torch of hope in the troubled world. It is a creative force which we must learn to utilize for the benefit of all mankind. This miracle of engineering skill which one day will bring the world to the home also brings a new American industry to serve man's material welfare ... [Television] will become an important factor in American economic life."

And how. On that fateful day in 1939, with America recovering from its greatest depression and war rumbling in the distance, Sarnoff gave the world a look into a new life. Not only was he instrumental in creating both radio and television as we know them, he was also nearly clairvoyant in seeing how each medium would develop. He regarded black-and-white TV as only a transitional phase to color and even predicted the invention of the VCR. His stubborn pursuit of technology turned his employer, Radio Corp. of America, into a powerhouse in less than a decade.

From Minsk, Russia To Marconi Wireless

But before television, Sarnoff had to create a radio network. And, not surprisingly, its formation was a circuitous route. Like many inventors, Sarnoff came from remarkably humble beginnings. Born in 1891 near Minsk, Russia, to a poor Jewish family, he immigrated, with most of his family, to New York City in 1900. In 1906, Sarnoff was working as an office boy in the Commercial Cable Company, which had strung transatlantic telegraph cables from Ireland to Nova Scotia, and onward to Manhattan. That September, when a superior refused Sarnoff unpaid leave for the Jewish holiday of Rosh Hashanah, he moved to another communications-oriented business, joining the Marconi Wireless Telegraph Company of America.

At Marconi, Sarnoff truly found a home, and would rise from office boy to commercial manager. During the 1910s, he installed wireless telegraph equipment on ships, on the Lackawanna Railroad, and even in the Wannamaker Department store in Manhattan.

His experience with wireless telegraphy led to his most important achievement at Marconi. Sarnoff would take radio out of the exclusive province of the transportation industry and embryonic ham radio hobbyists, and put it into every American home. There it would share space with the other appliances that the inventors of the early 20th century were delivering to increasing numbers of consumers.

Music Via Wireless — And a Network

In a memo, Sarnoff wrote "The idea is to bring music into the house by wireless." To do that, he needed a reason for people to buy these devices — in other words, programming. The classic radio shows our parents or grandparents told us about — starring early NBC celebrities such as Al Jolson, Jack Benny, and Bob Hope — all began with this decision. As did today's ESPN, Monday Night Football, and ABC's Wide World of Sports. Sarnoff's first program? A 1921 Jack Dempsey-George Carpentier boxing match. Its audience was a remarkable 300,000 listeners; the demand for radio took off exponentially from there. And by the start of the 1920s, General Electric had formed Radio Corporation of America to buy out Marconi — and Sarnoff.

Sarnoff's early radios weren't cheap. His first product for RCA — the Radiola — sold for $75, the equivalent of $850 in 2006 dollars, which illustrates both how inflation has dramatically increased prices. But it also demonstrates equally dramatically how the cost of technology has fallen: today, anyone can purchase a transistorized AM radio for about $20. But despite its steep initial price tag, radio was an immediate hit, leading to sales of $83.5 million in 1924. (The equivalent of over $900 million today.)

The stars that dominated radio were centered — as they are today — in New York (thanks to Broadway) and Hollywood (thanks to the movies). But

even the strongest radio signal has its limits. To get programming into the hands of consumers nationwide (and sell more radios), Sarnoff knew he'd need to build a network of radio stations across the country. Or as he dubbed it, the National Broadcasting Corporation, still going strong today as NBC. Like the other nascent radio networks that would form in its wake, it would make the jump to television in the late 1940s.

Radio, television, and NBC would eventually make Sarnoff an incredibly wealthy man, and quite rightly so. After leading NBC (and RCA) into the color television era in the 1960s, Sarnoff retired from RCA in 1970, and died the following year, at age 79.

The Life and Death of Mass Media

Like *Time's* own Henry Luce, Sarnoff was one of the pioneers of the era of mass communications, transforming America from a nation of local newspapers and pamphleteers into an era where brute technological force allowed a handful of networks of, first, radio stations to flourish, and then television, to create a near-uniform electronic mass media.

That era had its drawbacks, of course. When critics of the 1950s decry the seeming uniformity of "the man in the gray flannel suit" and his Donna Reed-styled housewife, they rarely note how much the limitations of communications technology played in creating that uniformity. In contrast, it's no coincidence that today's era of extreme cultural diversity coincides with the fracturing of the mass media by the rise of "The Long Tail" of the modern info-stream: thousands of narrowly focused magazines, hundreds of television channels, and millions of websites.

But what of AM radio, which Sarnoff wildly popularized? After a century that has seen the rise of motion pictures, radio, television, the Internet, and other media, we now know that no media fully destroys another. While most believed that the one-two punch of first television and then FM radio would bulldoze AM into obsolescence, it didn't quite happen, did it? Just ask Rush Limbaugh, Al Franken, and the other talkers making their own fortunes from a technology that David Sarnoff popularized nearly a century ago, that is still going strong. **NV**

by George Trinkaus

Vacuum Tube in its 100th Year: Same Old Challenges

The engineering challenges of the hot cathode vacuum tube — an invention dated 1906 — are the same today as they were then. The inventing of new, more compact and efficient vacuum-tube designs proliferated madly up until the 1950s, but the art has been frozen ever since. Before Fleming's diode and de Forest's triode Audion, inventors like Crookes, Tesla, and Roentgen had experimented with the magical effects of high voltage in vacuum. They created emissions of intense light and of strange rays, including x-rays. The "Fleming valve" was an evacuated glass envelope in which a light-bulb-style metallic filament — fed by low voltage and sucking high current — incandesced at 2,000°F. This created an electrical activity (or, in quantum parlance, "electron flow") that conducted unidirectionally through a vacuum to another nearby element — a metallic plate charged to a high positive potential. Thus was born a new rectifier, and hence, also a radio detector. Later, it was discovered that electrical activities within a tube could be leveraged at will by applying small fluctuations to a metallic grid interposed between the filament and plate (de Forest). Thus, human ingenuity created an amplifier, and hence, a modulator, an oscillator, a regulator, and an electronic switch. Also created was a means for huge magnifications by regenerative feedback (Armstrong).

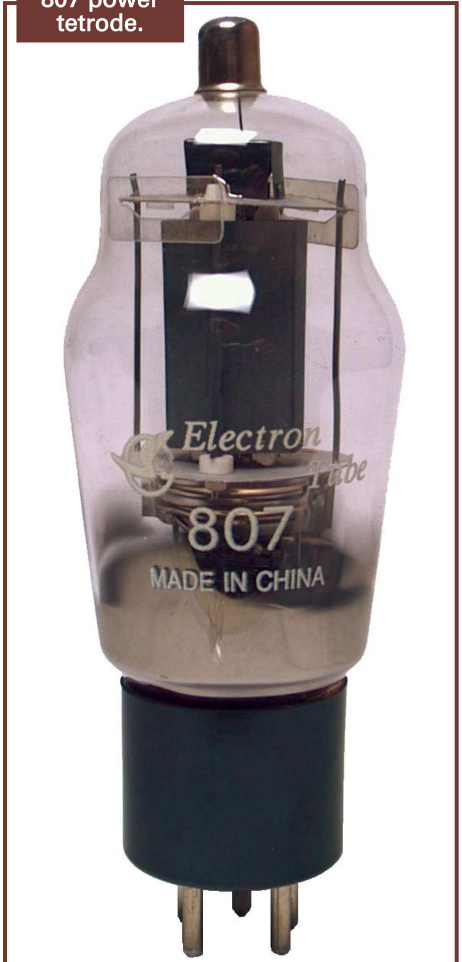


FIGURE 1. 807 power tetrode.

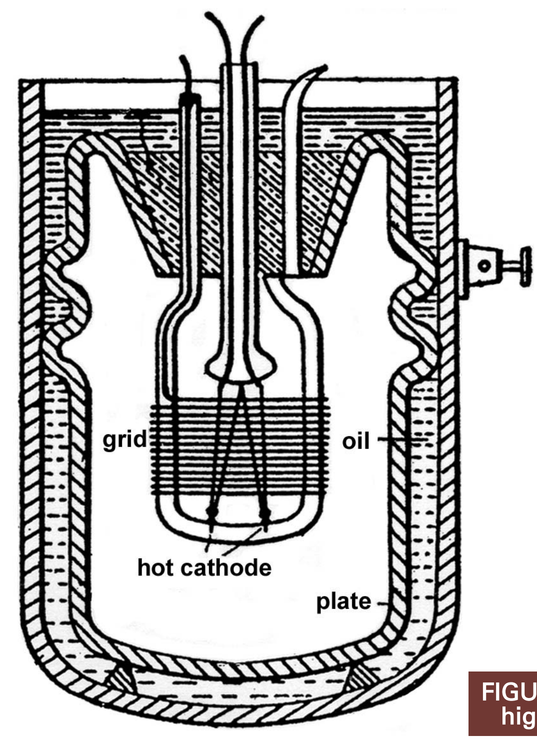


FIGURE 2. De Forest's high power triode.

Magnetic fields influence electrical phenomena within a tube, as in the magnetron and the cathode-ray. The vacuum tube became the foundation for almost all of electronics for the next 50 years. Until the mass production of the transistor in the late 1950s, electronics was the vacuum tube.

Post-transistor, the conventional hot cathode vacuum tube — despite its headaches for any engineer, builder, or user — has hung in there as a common choice for high-power transmitter finals. You can number this writer among those who revere the 811 and the 807 for this purpose. For the ham or broadcaster's kilowatt rig, the big 4-400A often wins

FIGURE 3. Popular power tubes.

out against the clustering together of power transistors.

The vacuum tube has seen a revival lately among audiophiles, who find in the vacuum tube ineffable qualities of depth, color, and warmth not found in solid-state.

Vacuum tube dealers still carry huge inventories of hundreds of types. Among the most popular are the 6L6, 6V6, 812, 12AX7, 12AU7, 12AT7, 300B, 6DJ8, 6922, and the 7308, as well as the types mentioned previously.

With a few exceptions, vacuum tubes are almost completely out of manufacture in the USA. Dealers often go to Chinese or Russian sources, like Sovtek. The Russian military has a special respect for tube technology and uses it in the electronics of aircraft, tanks, and ships. Why? Because tubes are 10,000 to 50,000 times more resistant than solid-state to destruction by an EMP.

Demanding

The hot cathode vacuum tube is a challenge to engineers and builders because of its heat (mostly generated by that hot cathode filament) and because of its demanding power requirements. Blower-cooling is often necessary to dissipate waste heat. Large currents from heavy iron-core transformers are required to fuel the cathodes of these fragile, glass-enclosed devices. Also, high voltages from special power supplies are required to fuel the plates: from 150 to 4,000 volts of well-filtered DC at a few hundred mA. Power supplies, and the transformers with which to build them, are expensive and hard to find.

The 6L6 power pentode takes 900 mA on the cathode heater and 250 to 360 volts on the plate. The 807 also takes 900 mA on the heater and requires 750 volts on the plate; the 811A, four amperes and 1,200 to 1,500 volts. The heaters of the one-kilowatt 4-400A suck a whopping 14 amperes with 4,000 volts on the plate. Its transformers are huge, ponderous, and expensive.

Because of the transistor's moderate power requirements, and because of its compactness, electronics engineers pounced upon the invention as soon as it went into broad manufacture in the late 1950s.

Similarly, in the early '50s, the magnetic amplifier (Figure 4) was seriously entertained, and even manufactured, as an alternative to the fragile vacuum tube. The mag amp was superior to the tube and transistor in current and voltage capacities, more simple (you could build one yourself), and far more rugged in all respects. (See "The Magnetic Amplifier, a Lost Technology of the 1950s" in the *Nuts & Volts* February '06 issue.)

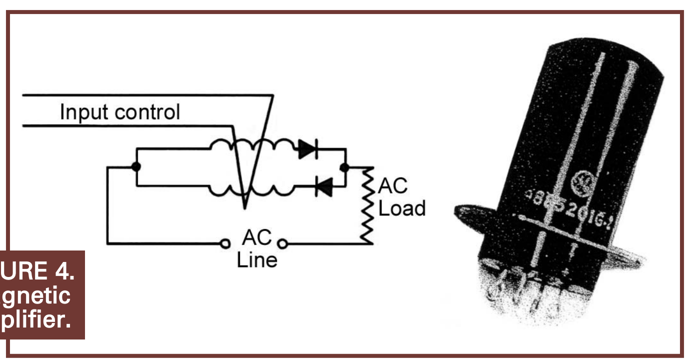


FIGURE 4. Magnetic amplifier.

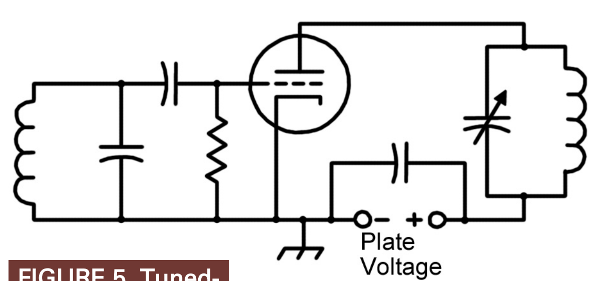


FIGURE 5. Tuned-plate-tuned-grid transmitter.

Internal Engineering

Appreciate the engineering challenges within the vacuum tube itself. Cathode temperature and plate potential are the key values in tube designing. The output ("emission") of a hot cathode depends upon filament temperature. So, it's desirable to achieve the highest possible temperature. Yet one must engineer the tube so it attains a long life before the delicate filament inevitably burns out and the tube becomes useless. So this sets limits to temperature.

The higher the plate voltage, the greater the electrical flow, but, at a certain high heat, there is a temperature-limitation barrier beyond which no increase in plate voltage will increase that flow.

Congestion of flow can also arise from an excessive build-up of electrical charge in certain spaces within the tube. This congestion sets a space-charge limitation to any conventional tube's performance. The proximity and shape of tube elements and the size and design of the envelope itself can enhance or mitigate space-charge problems.

Capacitance effects — especially at high frequencies — pose another design challenge. Each pair of tube elements constitutes a small capacitor that can affect amplification and oscillation. The larger the elements, the lower the frequency limit. Efforts to make the vacuum tube more compact created miniature and "acorn" tubes.

A tube can self-oscillate due to internal capacity effects. Internal capacity is exploited in a positive way in the power-amplifier circuit called tuned-plate tuned-grid (Figure 5).

A Cold Cathode Tube

In the 1930s, when some exploratory vacuum-tube engineering was still happening, P. T. Farnsworth obtained a series of patents on a cold cathode vacuum tube (Figure 6).

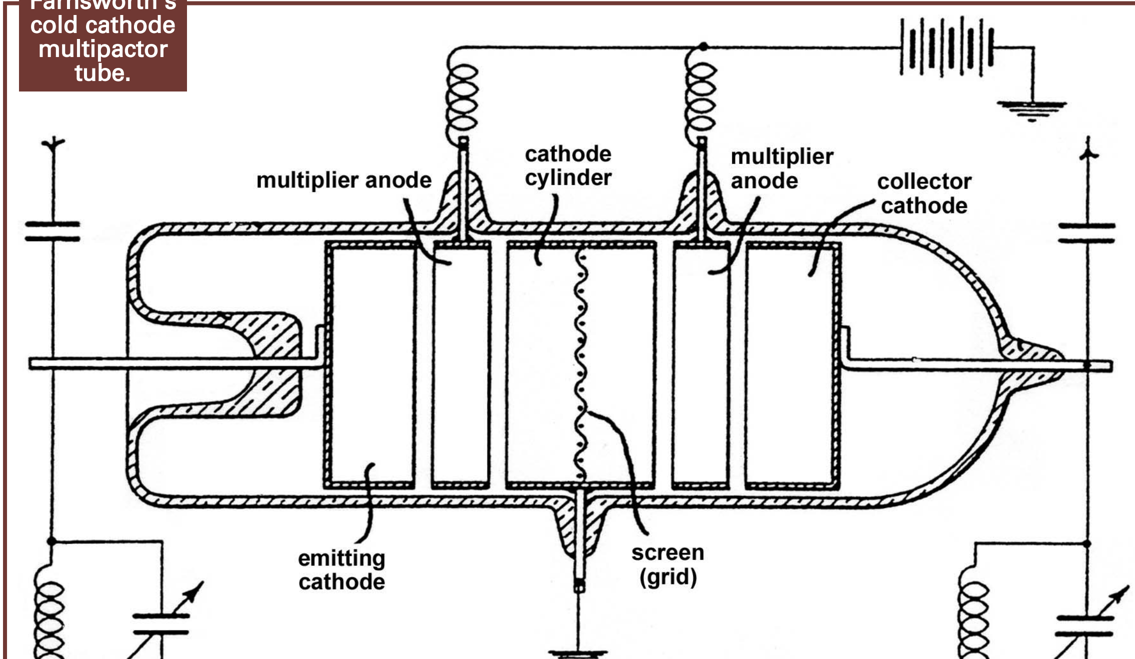
Farnsworth is known far and wide as the real inventor of television. (The history of radio is rife with rip-off: Tesla by Marconi, Fessenden by de Forest, Barreter by de Forest, Armstrong by de Forest, Farnsworth by Sarnoff.)

A cold cathode tube? But where does that necessary "cloud of electrons" come from?

Conventional tube theory and the whole history of the amplifying tube's development would have you believe that the only way electrical activity can be created in a vacuum is by "thermionic emission" from a hot cathode. (The same mythology prevails in traditional fluorescent lighting.) But Crookes didn't use hot cathodes in his evacuated spheres and tubes, nor did Tesla in his vacuum lighting devices or in his "rotating brush" detector. Effects are achieved by disturbances within the tube caused by the application of alternating currents, usually of high potential, generated by induction coils or by high-frequency Tesla coils.

Farnsworth's cold cathode multipactor amplifying and oscillating tubes were high-frequency inventions made for radio transmitting. Their range was 200 kHz to 60 MHz.

FIGURE 6. Farnsworth's cold cathode multipactor tube.



P.T. Farnsworth, Patent No. 2,091,439 (filed 1936). More Farnsworth multipactor patents: 2,071,516, 2,135,615, 2,141,827, 2,172,152 2,263,032, 2,174,487, 2,179,996. (found in *Vril Compendium 10*, Vassalatos, ed., borderlands.com)

Says Farnsworth in his patent, "All that is necessary to set the tube into oscillation, is to energize the anodes, as there will be, in the space between the cathodes, a sufficient number of free electrons which are accelerated toward one or both of the cathodes by the potential of the anode, to strike thereon and cause the initiation of secondary emissions."

The tube is tuned to resonance in a way analogous to the tuned-plate-tuned-grid transmitter shown in Figure 5. Some of Farnsworth's other patents show the tube set into a magnetic solenoid.

Over-Unity

Farnsworth said repeatedly in his patents that these devices are "over unity." Regenerative feedback and resonant reinforcement appear to be involved. The fact this device works without a hot cathode implies that plenty of electric energy can be set free in a vacuum tube if it is properly stimulated. (Free-energy seekers take note!)

Perhaps the invention's over unity potential explains why this novel tube never made it into manufacture, despite the fact that it liberated engineering from the problems of the old hot cathode. Did the invention just fall between the cracks like so many others? It did get a feature story in *Radio Magazine* (October 1934). Was the multipactor passed over because it was perceived as another "disruptive technology," like the electric car?

I've built a mag amp, but I've never been tempted to construct a vacuum tube from scratch. However, reading these old patents makes me want to go shopping for a vacuum pump. **NV**

ABOUT THE AUTHOR

■ *George Trinkaus wrote Radio Tesla and Tesla Coil and edited Tesla's The True Wireless and Magnetic Amplifiers. His High Voltage Press is at* ***teslapress.com****, (877) 263-1215.*

by Bob Armstrong

Vacuum Tubes for the 21st Century

If you've been reading this issue from the beginning, then you've already read a lot about the history of vacuum tubes. You might think that history is all there is to say about tubes, but it's not so. Hard as it may be to believe, there are still some applications today where a vacuum tube is a better choice than a transistor, and even a few applications where transistors simply aren't an option and a tube is the only choice available.

Medium Wave and Shortwave Broadcasting Tubes

High frequencies at high power levels — the higher the better — are still the domain of vacuum tubes and, if you're an engineer working at a radio or TV station, odds are that there will be a really big tube in your transmitter. Although they're conceptually no different from any other vacuum tube that you've read about, the scale of some of these broadcast tubes is amazing.

Eimac Corporation, in Palo Alto CA, manufactures broadcast transmitter tubes up to half a million watts. Photo 1 shows the Eimac 4CM500,000G. This tube is really nothing more than a basic power tetrode, but one with a rated plate dissipation of 500 kW! This tube also stands over two feet tall, is a foot in diameter, and weighs about 150 lbs. The filament of this tube alone requires 23V at 500A — that's almost 12 kW, or enough to power an average house.

PHOTO 1. Eimac 500 kW MW/SW Broadcast Tube.

UHF and Microwave Transmitting Tubes

The 4CM500,000G is only usable for medium wave and shortwave frequencies, but tubes rule at the other end of the RF spectrum, too. UHF television transmitters commonly use an Inductive Output Tube, or IOT, in the final amplifier. The IOT is a modern variation of the classic Klystron tube, originally invented by the Varian brothers in the 1930s, and is useful up to about 1,000 MHz at power levels of 75 kW or more.

Traveling Wave Tubes, or TWTs, are microwave oscillator and amplifier tubes that are used in satellite uplink Earth stations up to 30 GHz and several kilowatts of RF output. And, until very recently, a TWT was the only way to go for the downlink transmitter that's actually carried aboard the satellite itself. Believe it or not, there are many vacuum tubes orbiting the Earth now in the form of the TWTs in the downlink transmitters on board those satellites!

And finally, Crossed Field Amplifier tubes, or CFAs, are another specialized microwave tube. Similar to the familiar Magnetron, CFAs are very efficient and are generally used in radar transmitters. Since radar is a pulsed, short duty cycle application (i.e., transmit for a few microseconds, then listen for a relatively long time), large CFA tubes are able to generate pulsed outputs of many megawatts.

Microwave Ovens

The business end of the average microwave oven couldn't be simpler; all that it contains is a high voltage transformer, a simple diode and capacitor for the power supply, and a Magnetron tube. Any other complexity in the oven — keypads, displays, microprocessors, etc. — are there just to turn the Magnetron on and off at the right times. The beauty of the Magnetron tube is that it's able to serve as both oscillator and power amplifier and no other parts are required in this application. It's hard to imagine how this design could be improved by replacing this tube with solid-state devices.

The big brothers to the microwave oven in your kitchen are the industrial RF heating units. Industrial microwave

systems are used for drying everything from textiles to lumber, for curing adhesives and melting plastics, for food cooking, pasteurization and sterilization, and even welding.

Audio

Most of us are already familiar with the "glass audio" crowd — audiophiles who prefer the sound of vacuum tube amplifiers — but there's a flip side to this coin. All modern manufacturers of guitar amplifiers still feature vacuum tube amplifiers as a major part of their product line, and many of them are using designs that haven't changed substantially for decades.

Vacuum tube amplifiers exhibit a "soft clipping" when driven into overload, and this gives a form of distortion that's deficient in the harsh sounding odd order harmonics produced by solid-state amplifiers. Guitar players since the 1950s have intentionally over driven their amplifiers just to get this sound, and there are many classic vacuum tube amplifiers that are prized for the particular sound that they give.

Photo 2 shows the chassis of a brand new Peavy Penta guitar amplifier — notice that it's all tubes!

Displays

We've all seen those cute new LCD TVs and computer monitors, but did you know that CRTs still account for about three fourths of all television sales worldwide? The trusty old cathode ray tube is not only the cheapest display technology available, but it also has the brightest display, best contrast ratio, fastest response, and the best color rendition. New technologies like LCDs, plasma displays, and organic LEDs are making steady progress, but it will be a while before CRTs disappear.

While we're on the topic, vacuum fluorescent displays, or VFDs — those blue green numeric, alphanumeric, and graphic displays often found in appliances and automobiles — are also vacuum tubes. VFDs have a heated filament, a plate (the glowing segments) and, even in the case of multiplexed displays, a control grid.

PHOTO 2. The Peavey Penta Guitar Amplifier.

Gas Discharge Tubes

The Thyratron is a gas filled tube with a plate, cathode, and control grid that's used in on-off switching applications in much the same way that you'd use a silicon controlled rectifier. However, unlike SCRs, there are Thyratron tubes that are able to switch short pulses in the hundred megawatt (!!) range. Such tubes are used today to control pulsed radar transmitters and X-ray machines.

Another interesting feature of Thyratrons is that they can have a rise time — the time it takes the device to switch from off to on — that's on the order of a hundred times faster than an SCR. That fast switching time alone is enough to justify the use of a Thyratron in applications such as "crowbar" circuits for high voltage power supplies or firing circuits for pulsed lasers, even where solid-state devices could otherwise handle the power levels involved.

Two specialized Thyratrons — the Krytron and Sprytron — are able to switch in subnanosecond intervals. This sounds like an esoteric concern, but, in fact, it makes them ideal for triggering explosives, particularly in situations where multiple charges need to be detonated with precise timing. This is exactly the situation you'd find yourself faced with if you were building an atom bomb, and Krytrons were used in the detonator for the original Fat Man bomb. Obviously, I don't know whether they're still used for this purpose today, but the sale and export of Krytrons and Sprytrons are tightly regulated by the US Government.

And, although they aren't really vacuum tubes in the sense that we're talking about here, it's worth pointing out that the ubiquitous fluorescent lamps, mercury vapor lamps, and low pressure sodium street lamps are all gas discharge tubes. Neon signs, Xenon flash lamps, and even gas lasers all also belong to this category.

X-Ray Tubes

One of the oldest forms of vacuum tube — the X-ray tube — has been around since the late 19th century. Besides the obvious application of medical imaging, X-ray tubes are used today for security scanners (we've all seen those at the airport), food inspection systems, thickness gauges, and more.

Vacuum tubes are also still useful

PHOTO 3. S11 X-Ray Tube. Photo courtesy of Source 1 X-Ray.

MORE READING

- Eimac Division of Communications & Power Industries (CPI), **www.Eimac.com**.
- Peavey Electronics Corporation, **www.Peavey.com**.
- Usenet, **http://groups.google.com/group/rec.antiques.radio+phono**.
- Brand X-ray Tubes, **www.brandx-ray.com**.
- Source 1 X-ray Tubes, **www.source1xray.com/xraytubes.htm**.
- Industrial Microwave Systems, **www.industrialmicrowave.com**.
- Industrial Microwaves and Magnetrons, **www.industriellemikrowelle.de/Eng_s1.htm**.
- "CRT Still Rules TV Market," *Electronic News*, 6/5/2006.
- "CRT Not Ready for the Museum Shelf," *Electronic News*, 5/25/2005.
- "Design of a 250MW Hydrogen Thyratron," *IEEE Pulsed Power Conference*, 1993.
- "The Great Krytron Caper," *The Washington Report*, July 15, 1985.
- Nautel solid-state broadcast transmitters, **www.nautel.com**.
- Harris solid-state broadcast transmitters, **www.broadcast.harris.com**.
- Nixie Tubes, **http://groups.yahoo.com/group/NEONIXIE-L/**

as detectors for x-rays and other ionizing radiation. The most obvious case is the Geiger Müller tube which is at the heart of a Geiger counter, but scintillation detectors also use photo multiplier tubes to detect the tiny flashes of light that occur when radiation strikes a radio luminescent crystal.

Oil Wells

One of the most interesting applications I came across while researching this article are the so-called "down hole" instruments used in the oil industry. Not surprisingly, it's really, really hot at the bottom of an oil well — temperatures at the bottom of a several miles deep borehole can reach over 400°F — and, until very recently, solid-state devices were unable to survive in this environment. But on the other hand, Nuvistors — a miniature, all metal vacuum tube invented in the 1950s for UHF applications — can operate up to 500°F or more. Nuvistors were used in down hole instruments up into the 1990s and have only been supplanted by solid-state devices in the last decade.

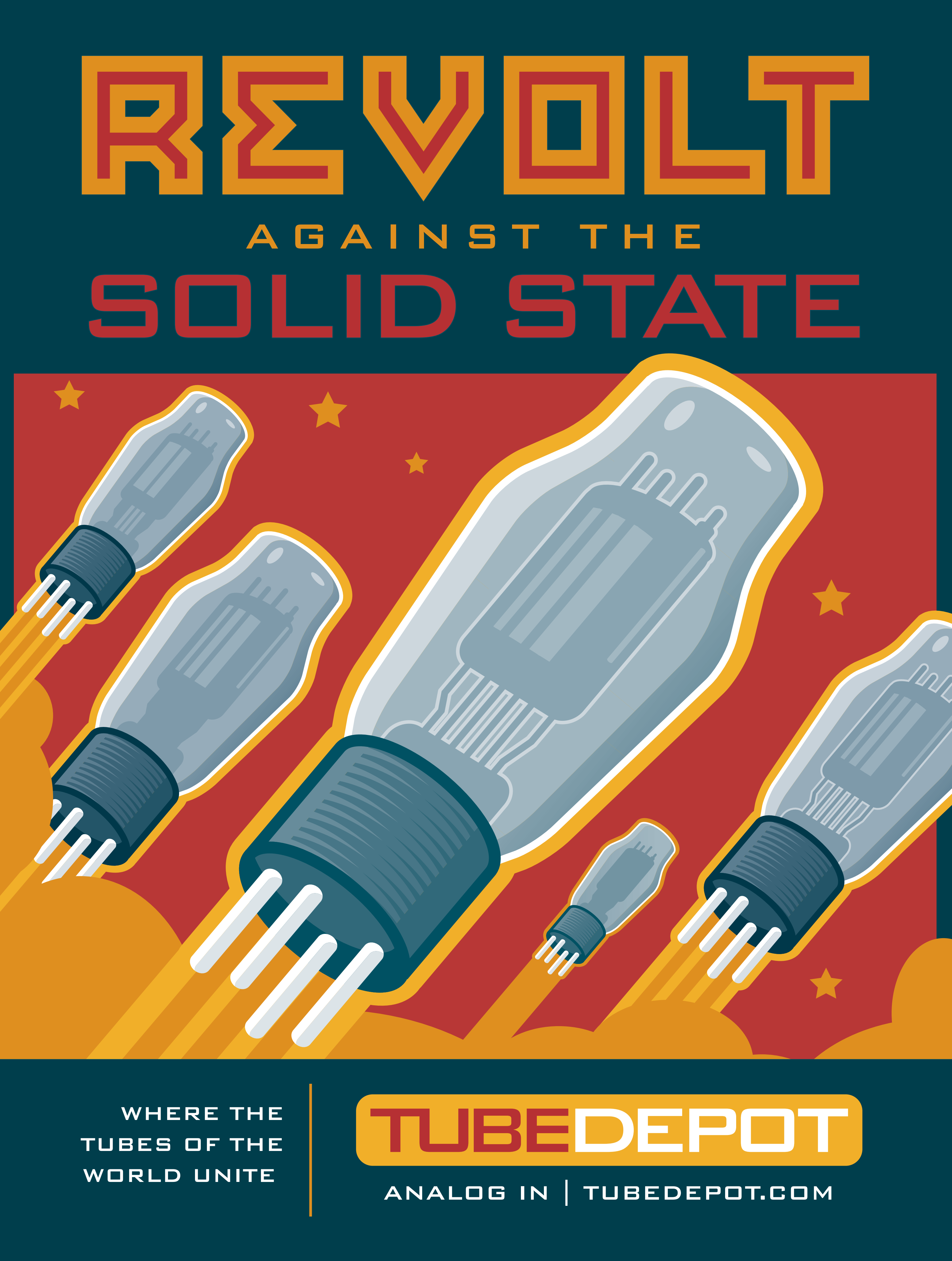
The Future

I wanted to end by saying that vacuum tubes would be with us forever, but it's not that simple. Many of the applications I've mentioned are slowly but surely being overtaken by solid-state devices. LCDs are steadily replacing CRTs, and it won't be that long before CRTs disappear.

There are already several, completely solid-state MW/SW broadcast transmitters in the hundred kilowatt range, and there are a number of solid-state alternatives to TWT transmitters for satellite links. The latter are generally much lower power than their TWT ancestors — transistors are still not good for high power levels at microwave frequencies — but for satellite Earth stations, the gain of a 10 meter dish obviates the need for lots of power.

Even the guitar players may switch eventually — Peavey engineers have studied gain, response, compression, and several other factors that create the "tube sound" and have come up with a line of "TransTube" all solid-state amplifiers.

But there are still some applications that are safe for the foreseeable future. For one, nobody has come up with an X-ray LED (at least not yet!). And it's hard to imagine how a solid-state replacement, even if one existed, could be simpler or more reliable than the magnetron in your microwave oven. **NV**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by Terry Turner

The Antique Wireless Museum

For anyone interested in electronics, its history, and development, a trip to the Antique Wireless Association Museum is a must.

The museum is located in the small and picturesque town of Bloomfield, NY and features some of the most unusual and rare exhibits of wireless, telegraph, radio, and television ever assembled. The museum is one of the few devoted to research, preservation, and documentation of the history of wireless communications.

Even the building housing the museum has a unique history. It's a former school built in 1837 and is a celebrated landmark of the Finger Lakes region of New York. Its brick exterior and hardwood floors hearken back to days gone by of crystal sets and long-wire antennas. The Bloomfield, NY Historical Society has their offices on the first floor of the building and the AWA Museum fills the second and third floors.

Upon entering the museum, the first stop on the tour is the 1925 radio store where, without much effort, visitors can use their imaginations to transport themselves back to a time when radio was brand new. Museum curator Ed Gable said the history of broadcasting began in radio stores like the one on display at the museum. "At that time, there was literally zero radios at home," Gable said. "Before that, it was all commercial, military, point-to-point, and nothing in the home. What fascinates me is that five years later, there were five million radio sets in the home and half of those were homemade." He said consumers could go to the radio store and buy components to build their own radio or choose from a wide variety of factory-built sets.

Building an early radio set or listening to it was something that brought families together Gable said. "Fathers and sons building radios on the kitchen table was common at that time. The reason they built them on the kitchen table instead of the basement or garage was that they had to heat up the soldering iron on the gas stove."

Those early radios, of which the museum has several working examples, were not easy to operate. "We like to show people how you had to tune each dial exactly right," Gable said, "and if you got it wrong, you could go all day long and not hear a thing. People really had to want to listen to radio. Not only was it hard to operate, but you had all the batteries to deal with. Typically, there was a six-volt car battery and it was the young lad's job in the household to take the battery down to the automobile garage and have it charged up so they could listen to the radio all weekend long."

Also on display are examples of communication equipment used prior to the development of radio broadcasting. The maritime and shipboard display features spark transmitters from the early 1900s. "They were about 1,000 watts and they worked about 1,000 miles," said Gable. "About a mile a watt. They were pretty crude, but they worked well."

Gable said there is a definite point in the period of early wireless broadcasting where the importance of this new form of communication became dramatically apparent. "As historians, we talk about the pre and post Titanic era," Gable said. "We have a model of the Titanic radio room here because of the important role the 1912 Titanic disaster played in the development of radio." He said that although Marconi had developed wireless sets that were successfully used aboard ships, there were no laws or regulations governing the operation of the equipment. "So there's the poor Titanic and it's sinking and they're

The Antique Wireless Museum in Bloomfield, NY is housed in a former school and celebrated landmark of the Finger Lakes region of New York, built in 1837.

sending SOS like mad," said Gable. "Even though there were ships in the area that could have heard their signals, the operators had gone to bed. At that time, there was no requirement for them to be on the air and monitoring." After that tragedy, regulations were developed to make sure distress signals were heard and, at the same time, new equipment was developed and became available.

Also on display at the museum is an early example of a police radio. The first radio sets installed in police cars were just receivers. "That was back in the days when you heard, 'Calling all cars ... bank robbery at First and Elm' and that was exactly it because all they did was transmit," Gable said. "The cars could not talk back. If they had to call back to the station they would have to go to a telephone call box. The frequency range was just above the broadcast band. On a lot of the old radios of the 30s and 40s at the top of the broadcast band, you'll see something labeled 'police' and that's what it was."

Because the major manufacturing center for early electronic communication was located in nearby Rochester, NY, the museum was able to acquire a great many of the examples of those first experiments in radio. For example, on display at the museum are the actual breadboards for the regenerative receiver, the superheterodyne receiver, and FM transmitter built by Howard Armstrong and his assistant.

Not all the experiments in radio were successful, of course, and some of those are also on display. One is the first attempt to design a high-fidelity AM broadcast transmitter. "It was a total failure," Gable said. "They were desperately trying to improve the fidelity of the broadcast industry. The people who developed it had the idea to broaden the bandwidth to get it nice and wide to get lots of fidelity. Then they had to broaden the receivers, but all they did was make it more susceptible to more noise."

Jack Roubie, Facilities Manager for the Antique Wireless Museum in Bloomfield, NY works on restoring one of the many radios in the museum's well-equipped shop.

Visitors to the AWA Museum can see an example of the very early days of television development with a working example of a television transmitter and receiver. "It's a 1927 all mechanical TV system," Gable said. "There are probably only a few of these anywhere that are working." The mechanical television was the brainchild of prolific inventor Charles Jenkins. Gable said the amazing thing about the mechanical television is that while Jenkins was building his system in the United States, across the Atlantic a very similar system was being developed by John Logie Baird in England. "The two progressed almost identically with the same methods and procedures and they never knew the other existed," Gable said. "It was incredible the way that happened."

Jenkins used his mechanical system to broadcast a program for about two hours every night. The entertainment value was limited and was intended mainly for hobbyists and experimenters. "It was on the shortwave band," said Gable, "and he covered the entire Northeast from the Washington D.C. area. It was a fairly low frequency of about 3 MHz."

Also on display in the television area are various models of early TV sets, including one used by David Sarnoff of RCA to test signals broadcast from New York. Sarnoff went on to become president of RCA in 1930 and in 1947 he was the CEO of the company. He was also instrumental in forming NBC — the first radio network.

Almost as soon as black and white television was perfected, work began on developing a color system. The AWA Museum chronicles the early battle among designers and networks to come up with a suitable color television system. On display is a mechanical color television system developed in 1946 that produced color pictures by having a spinning wheel with red, blue, and green filters in front of a cathode ray tube. "The transmitter would send red, blue, and green information and your eyes would average it out," Gable said. "And it had beautiful color. It was actually far superior to the early RCA three-gun system."

It was quickly realized that, although the system worked well with a 10-inch screen, eventually consumers would demand larger screens which would require a huge spinning disk. "For a 21-inch set, the wheel would have to be 13 feet in diameter spinning at 300 RPM in your living room," said Gable with a laugh. This mechanical means of producing a color picture was used in 1949 to broadcast medical procedures from Pennsylvania and Atlantic City hospitals. In Atlantic City, viewers could come to the convention center to see broadcasts of operations. Reports from the time noted that the realism of seeing surgery in color caused more than a few viewers to faint.

The Antique Wireless Association Museum has large number of displays

dedicated to the telephone. The museum has the first subscriber telephone dating back to 1877. "There were just two of these," explained Gable, "and there was no operator. Just two telephones and a battery." The direct connection with no ring capability had the obvious disadvantage that a time had to be arranged in advance to tell the other person when to expect a call. "It was very similar to the old tin can and string but worked a little better," Gable said. "They were used mostly by industry and banks."

One corner of the museum is dedicated to inventor and electrical engineer Edwin Howard Armstrong. Armstrong's first contribution to radio was the regenerative circuit which he invented in 1912 and provided better amplification and fidelity. "It vastly improved radio reception capability," said Gable. "His second contribution was the superhetrodyne receiver which is something we enjoy even today in radio. The third one goes along with the quest for high fidelity broadcasting or the elimination of static. And that was FM."

Armstrong had an assistant — Harry Houck — with him for most of his career and, fortunately for those interested in the history of radio, sometimes Harry didn't follow directions very well said Gable. After the development of each of the circuits that contributed so greatly to radio, Armstrong told his assistant to take it apart and throw it away. "Harry Houck didn't do that," Gable said. "He took the stuff and kept it in a box for 30 years." It was then Houck, who was a member of the AWA decided to share those historic items with several museums including the Antique Wireless Association Museum. "So in little downtown Bloomfield, NY," said Gable, "is the world's first regenerative receiver, the major part of the world's first superhetrodyne receiver, and the world's first FM transmitter."

Gable said Morse Code was originally developed to be detected by machine not human hearing. "You'll see all over the museum examples of devices used to copy and print out Morse Code." He said it was a Morse Code instructor in Syracuse, NY who first began copying code by hand. "He began listening to the sounder and got to where he could copy the code," Gable said. "The machines were temperamental and were always breaking down and he got good at it and became a proponent and teacher of copying code."

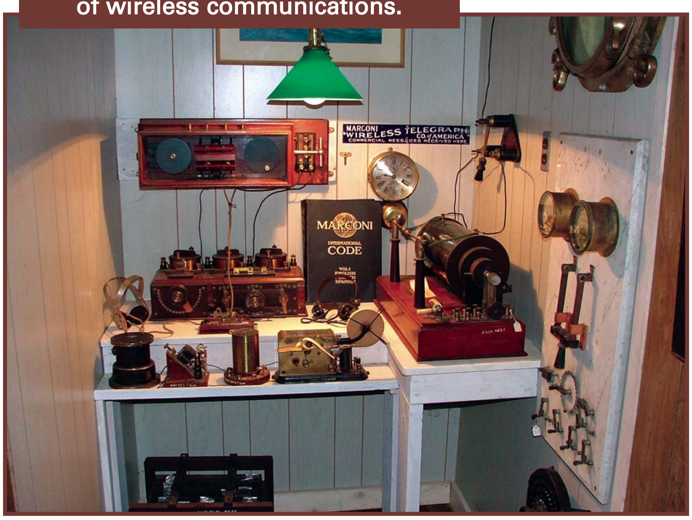
The AWA has a unique program for getting radios restored called, "Adopt a Radio." Gable said the AWA has a convention every year and during that event people have an opportunity to participate in the program. "They can look at some radios we have set up in the annex and they can take it home for a year, work on it and restore it, and then bring it back the following year. It gives people a chance to work on radios they may never have an opportunity to work on. And, of course for us, it gets our radios restored. So it's a win-win situation." The restored radios are then put on display in the museum.

One area of the museum is dedicated to military communications with some rare items like a 1916 spark transmitter used by artillery spotters. Included in the display are a large number of items from World War II. One stands out from the rest. "It's a Model 19 set," explained Gable. "It has Russian characters on it. It was designed in England, built in America, and used by the Russians."

Also on display is a huge collection of vacuum tubes including one of the very first vacuum tubes built in 1905 by John Ambrose Fleming. One unusual tube on display was developed out of necessity, said Gable. "In those early days there had to be a way to pay for radio. In the US, we decided to sell advertisements, but in England and Canada, you bought a license. In Germany, you paid a tax on the number of tubes in a radio. And if you look at this tube, you'll see condensers and resistors in there. They built the whole radio in a tube. So you only paid tax on one tube."

The museum also tells the story of the transistor. The transistor was first developed by Bell Labs for use in the telephone industry. Bell Labs naturally wanted the radio industry to start using transistors instead

The AWA Museum has a model of the Titanic radio room because of the important role the 1912 Titanic disaster played in the development of wireless communications.



AWA Museum Curator Ed Gable operates the museum's spark transmitter.

of tubes. "They had a heck of a time trying to get a transistor to work all the way up to 100 kHz," Gable said. They were finally successful and constructed a small portable transistor radio as a demonstrator. That radio is on display at the museum and the AWA has all of the original engineering documentation to go with it. "They took it on the lecture circuit to show anyone who wanted to listen. They sold the rights to several manufacturers including Regency who made the TR-1 (the first commercially produced transistor radio) in 1954." That first transistor radio put together by Bell Telephone to demonstrate this new technology to potential investors is on display at the museum.

Many of the displays allow visitors to actually operate the equipment. They can talk to one another on 19th century phones and with the help of a guide can watch and hear spark transmitters in operation.

The Antique Wireless Association Museum is open May through October on Sundays from 2 pm to 5 pm. The museum is also open on Saturdays from 2 pm to 4 pm from June through August. The museum is closed on holiday weekends. Admission is free. The AWA Museum is located at 2 South Ave., Bloomfield, NY.

For more information about the Antique Wireless Association Museum, visit their website at **www.antiquewireless.org**, call Edward Gable at (585) 392-3088, or email him at egable@rochester.rr.com. **NV**

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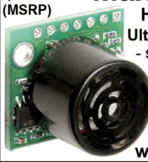

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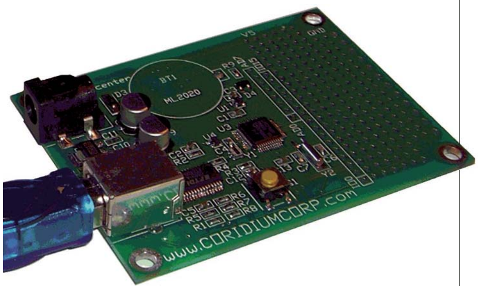

Coridium Corporation introduces the ARMmite, the second in the ARMexpress family of 60 MHz CPUs running compiled Basic. The ARMmite is a single board computer priced at $49. It has a built-in USB connection for programming from a PC. The NXP LPC2103 is used for the CPU. Basic programs are compiled on the PC and downloaded to the ARMmite. As the code is compiled to ARM instructions, Basic user programs run faster than 10 million instructions per second; 12K is available for user code and 6K for variables.

The 20K library provides support of the popular SPI, I²C, 1-Wire, and ASYNC protocols. This allows control of serial peripherals at rates of up to 1.4Mbits/sec. The library also includes PWM, SHIFTIN, SHIFTOUT, PULSIN, PULSOUT, and FREQOUT functions with one microsecond resolution. ARMbasic also contains string functions of concatenation, STRCOMP, LEFT, RIGHT, HEX, and VAL functions.

The Basic language is simple to learn and is perfect for those tasks that require a quick solution, such as gluing instruments and sensors together on the factory floor, as a flexible lab bench tool, educational applications, and uses by hobbyists. Time to market is an essential issue, and for many problems the ARMexpress family is a good match for those small volume applications, combining ease-of-use and high performance in a cost-effective package.

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■ BY PETER BEST

"DISCOVER"ing DHCP MESSAGES

I'LL BET THAT MANY OF YOU TOOK MY ADVICE to heart and read through the DHCP RFC documents. If you did, you now know that there are mountains of rules and recommended procedures for implementing DHCP. The good news is that I've sifted through all of that stuff and gleaned only the essential DHCP stuff we'll need to allow a microcontroller to play in DHCP land. The information that I milked out of the DHCP RFC documents will be used to form the basis of our DHCP source code, which we will write in this spin of Design Cycle.

In previous Design Cycle offerings, we've looked at various Internet protocols and in the process of discussing them, we also wrote some code to implement them. For instance, we already have a working ARP (Address Resolution Protocol) code module, a working UDP (User Datagram Protocol) code module, and a working TCP/IP (Transmission Control Protocol/Internet Protocol) code module. We also already have a stable Ethernet hardware platform to work with the Frame Thrower II, which is based on the new Microchip ENC28J60 Ethernet IC. If this is your first jump into the Design Cycle, you can get all of the ENC28J60 stack code we've written in past Design Cycles from the *Nuts & Volts* website (**www.nutsvolts.com**) or the download area of **www.nerdvilla.com**.

The ENC28J60-based Frame Thrower hardware we're targeting can also be had from either **www.edtp.com** or **www.nerdvilla.com**. As you would expect, all of the code we generate during the course of this column will also be available from both the *Nuts & Volts* website and the download area of **www.nerdvilla.com**. As an extra bonus, I've listened to you, the reader, about your concern with high-cost projects. To keep costs down, you can get a special *Nuts & Volts* reader discount if you order your Frame Thrower hardware by way of the NERDVILLA site.

The DHCP code we will construct will follow along with the DHCP state diagram shown in Figure 1. The ENC28J60 hardware initialization is handled within the ENC28J60 garage stack code that is available for download. So, our first real goal is to write the code to put a DHCPDISCOVER message out onto our network.

BUILDING A DHCP DISCOVER MESSAGE

Do you recall the term encapsulation? DHCP messages are actually payloads of UDP datagrams. UDP datagrams are payloads of IP datagrams. So, to build a DHCP DISCOVER message, we must generate an IP datagram and a UDP datagram. The code to do this is a bit too lengthy to show you in print. So, to follow along with the DHCP DISCOVER message buildup explanations, please download a copy of the DHCP source from one of the websites mentioned. The DHCP DISCOVER message code can be found within the send_dhcp function of the DHCP code you download.

The entire DHCP DISCOVER message will be assembled within the transmit SRAM area of the ENC28J60. The send_dhcp function begins by directing the ENC28J60 EWRPT (transmit area write pointer) registers to point to the beginning of the actual transmit SRAM, which is contained within the ENC28J60. We will burst the DHCP DISCOVER data into the ENC28J60 by keeping the ENC28J60's SPI interface engaged until we are done sending data. Once the ENC28J60's SPI interface is activated, a WBM (Write Buffer Memory) command is issued to the ENC28J60.

The first byte that must be written is the control byte (0x0E). The tx_end variable is incremented as each byte is written to the ENC28J60 transmit buffer. We will ultimately use the tx_end value to determine the end of the data to be transmitted within the ENC28J60's transmit buffer. The tx_end value will also be used to determine the values that will populate the IP and UDP length fields.

Once the initial 0x0E control byte is written, the rest of the process is simply the assembly of a standard Ethernet frame. The first real data we must provide in an Ethernet frame is the destination hardware address. In the case of a DHCP message, the destination hardware address is a broadcast address, which is six bytes of 0xFF. Every DHCP message that is sent by our Frame Thrower II is identified by the source hardware address of 00-00-46-54-49-49 hexadecimal, which translates in ASCII to 00FTII, with leading zeros not alphabetic "OO." The six-byte Frame Thrower II hardware (MAC) address follows the destination hardware address into the ENC28J60's transmit buffer. Two bytes (0x0800)

are then written to the ENC28J60 transmit buffer to indicate to the receiver that the Ethernet frame contains an IP datagram. The Ethertype field (0x0800) signals the end of the DLC (Data Link Control) data.

Our next task is to build the IP header. After all, this is an IP datagram we're assembling. If you're following along with the DHCP source code, the code following the comment //BEGIN IP HEADER fills in the IP header fields, which include, among other things, the protocol type (UDP) residing inside the IP data area and the source and destination IP addresses. When we're done with the complete Ethernet frame, we'll come back and populate the IP packet length field and calculate the value for the IP header checksum field.

The last field we touch within the IP header is the destination IP address field, which is a broadcast address of 255.255.255.255. Remember, we don't yet have an IP address of our own. So, the source IP address field in the IP header is populated at this time with 0.0.0.0. Note in the DHCP source code that tx_end is updated to reflect the length of the IP header before we move on to build up the IP data area, which contains the UDP datagram.

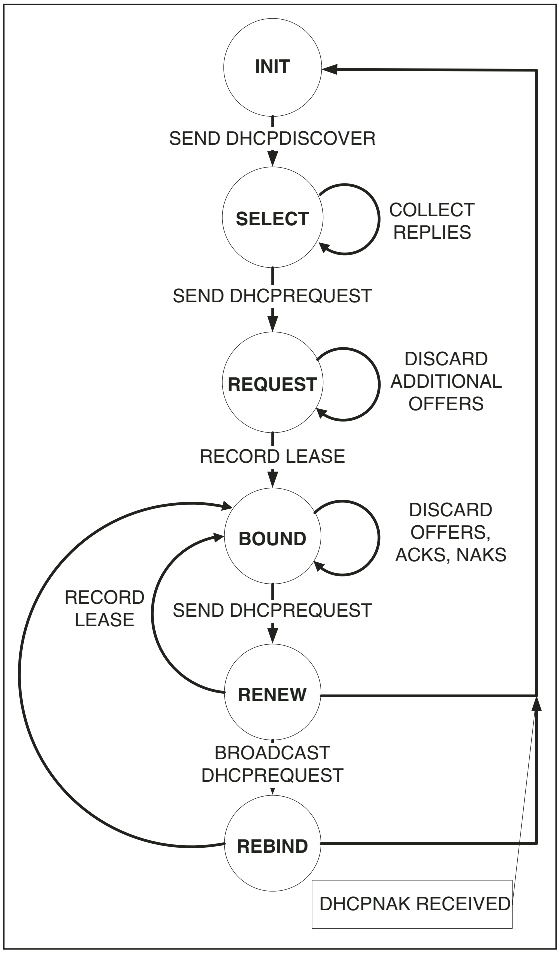
The first two bytes of the UDP header represent the UDP source port, which happens to be, in this case, the DHCP client address of 0x0044, or 68 decimal. The next two bytes written to the ENC28J60 transmit SRAM area contain the UDP port address of the DHCP server, 0x0043. Once the Ethernet frame is completely populated with values we must provide programatically, we will use the tx_end value to compute a value for the UDP header length field. No UDP checksum is used and the UDP checksum fields are loaded with 0x0000. The UDP header is eight bytes in length and that is added to the cumulative tx_end value.

I posted a graphic depicting the fields of a DHCP message at the beginning of the DHCP message code in the send_dhcp function. You should be able to follow along in the code easily with the guidance of the DHCP message graphic as the code populates the fields in the order shown in the DHCP message graphic. I have assembled a set of DHCP flag bits to help with identifying certain DHCP events that we must keep logical track of. The clr_offerrec (clear offer receive bit) macro is used in the DHCP DISCOVER message code to signal that no DHCP offers have been received from a DHCP server. When the offerrec bit is set, this indicates to the code that a DHCP offer has been received. You can see the complete set of flags by examining the beginning of the DHCP code listing. The DHCP flags are named to make their function obvious to the most casual observer.

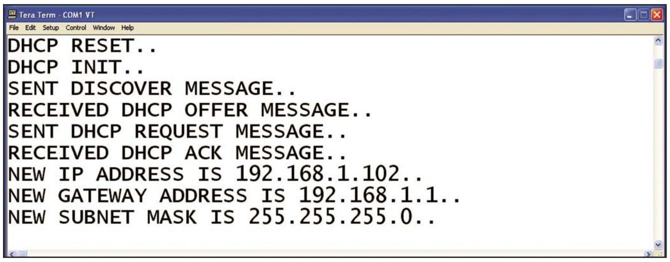
The 0xFF within the DHCP message signals the end of the DHCP message and the end of the IP datagram. The next thing we must do is calculate the total length of the IP datagram and write this value into the IP datagram length field, which is offset 17 bytes (0x0011) into the Ethernet frame we have built within the ENC28J60's transmit SRAM area. Remember we have to count the initial control byte (0x0E) into our offset calculations as it is actually written at the top of our Ethernet frame inside the ENC28J60's transmit data area. Thus, our IP datagram length is equal to the accumulated value of tx_end minus the 14 bytes of DLC data plus the control byte. The calculated IP datagram length value is written to an offset within the ENC28J60 transmit area, which is calculated using the value of TXSTART (the beginning physical address of the ENC28J60's internal transmit area), plus the offset value of the IP datagram length field (0x0011).

The UDP datagram length, which represents the length of the UDP header plus the length of the UDP data — which is really our DHCP message — is calculated in a similar manner to that of the IP datagram length. The UDP datagram length is the accumulated value of tx_end minus the sum of the length of the IP header (20 bytes) and the control byte/DLC data (15 bytes). The UDP datagram length is written to the UDP datagram length field, which is at an offset of 0x0027 bytes into the Ethernet frame inside the ENC28J60 transmit data area.

The computation of the IP header checksum is one of the neatest things in the DHCP code because the checksum value is calculated by the ENC28J60 hardware. We already have a very good coded checksum routine that we used in the previous Design Cycle columns to compute checksums for IP, TCP, and UDP. However, to use our coded checksum routine, the data to be used in the checksum must reside in the PIC's SRAM. In this case, our data to be used in the checksum calculation is loaded in the ENC28J60's SRAM. We would have to read the data from the ENC28J60 SRAM into the PIC SRAM to perform our coded checksum function. The ENC28J60 hardware eliminates the



■ FIGURE 1. This is how DHCP works. If we can write code to walk through all of the states, we will end up with enough information to participate in any network that we are offered to join.



■ PHOTO 1. If you examine the DHCP code, you'll see how all of these messages were generated. Note the messages correspond to the states in Figure 1.

need for us to do the ENC28J60-SRAM-to-PIC-SRAM transfer by incorporating its own hardware checksum functionality. The use of the ENC28J60 internal checksum function not only saves a ton of time, it's easy to set up and use.

We already know that the beginning of our IP header begins at an offset of TXSTART plus 15 bytes. That's where our IP header checksum data area begins and this checksum-begin offset value is loaded into the EDMAST (DMA Start) register pair (EDMASTH/EDMASTL). Our IP header is 20 bytes long. So, beginning at a count of 0x00, we add the IP header length minus 1 (byte 0 through byte 19 is 20 physical bytes) to the offset value we loaded into EDMAST and load this value into the EDMSND (DMA End) register pair (EDMANDH/EDMANDL).

Loading the DMA start and DMA end register pairs delimits our checksum data area. Now all we have to do is kick off the checksum calculation. If you're wondering what DMA (Direct Memory Access) has to do with checksum calculations, the ENC28J60 uses its DMA engine to calculate checksum values. Checksums are calculated within the ENC28J60's DMA hardware by roping off the bytes to be included in the checksum calculation and setting the CSUMEN (Checksum Enable) bit and the EDMAST bit in the ENC28J60's ECON1 register.

The 16-bit IEEE-standard checksum value is returned in the ENC28J60's EDMACS register pair (EDMACSH/EDMACSL). Once we have the checksum value, all we have to do is plug it into the IP checksum field 25 bytes into the Ethernet frame data we've already put into the ENC28J60 transmit SRAM area.

The last thing we must do before we send our DHCP DISCOVER message along is set the end of the ENC28J60's transmit buffer area using the tx_end value coupled with the TXSTART offset value.

According to Figure 1, the next thing that should happen is that the DHCP server returns a DHCP OFFER message in response to our DHCP DISCOVER message. That's assuming we did everything right in our DHCP DISCOVER message. I sincerely hope there was absolutely no doubt in your mind as to if we have done everything correctly up to this point.

PROCESSING THE DHCP OFFER MESSAGE

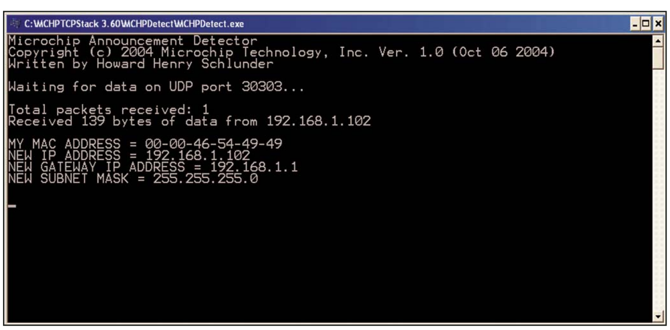
The Linksys AP (Access Point) returned a DHCP OFFER message in response to our DHCP DISCOVER message. So, turn your attention to the receive_dhcp function in your DHCP source code package. In our DHCP DISCOVER code, we cleared the offer received flag (clr_offerrec). Since the offer received flag is clear, the first thing our DHCP receive code does is collect the offered IP address from the DHCP message's yiaddr (your IP address) field. To make sure this offer is really ours, the DHCP receive code checks the contents of the chaddr field against our hard-coded MAC address. Once the DHCP OFFER message is confirmed as belonging to the Frame Thrower II, the captured DHCP message is parsed to harvest the DHCP message type (DHCP OFFER MESSAGE), the IP address (192.168.1.1) of the DHCP server (Server ID), the network subnet mask (255.255.255.0, in our case), the DHCP lease time (24 hours), and the gateway IP address, which happens to be our Linksys AP IP address (192.168.1.1). All of the values we have been given are considered temporary until we issue a DHCP REQUEST message asking to be granted the use of the lease values in our possession.

Dial your eyes into the dhcp_state_engine function. Work your way through the logic of the dhcp_state_engine function and you'll find that we are now in the DHCP_REQUEST state and we need to send a DHCP REQUEST message to move to the next DHCP state. Figure 1 also says that we are ready to issue a DHCP REQUEST message to the Linksys AP. Since we only have one AP/DHCP server in our little network, we only received a single DHCP OFFER reply in response to our DHCP DISCOVER message and we accepted the DHCP offer included within the reply.

The dhcp_state_engine function initiates the transmission of a DHCP REQUEST message and enters the DHCP_BIND state awaiting a DHCP ACK message from the Linksys AP. The same logic we used to send a DHCP DISCOVER message is used to send the DHCP REQUEST message. Follow the send_dhcp function and take the DHCP REQUEST logic turns and you'll see that an option in the DHCP message structure is included to officially ask for the offered IP address. If we've assembled our DHCP REQUEST message correctly, the next thing we should see is a DHCP ACK message in response to our DHCP REQUEST message.

A GO FOR DHCP

Looky here! The Linksys AP returned a DHCP ACK message. Now we can move all of those temporary



■ PHOTO 2. This is gravy. The display is a result of a simple UDP datagram sent to UDP port address 30303 as an IP broadcast message.

values into permanent locations for use during the extent of our DHCP lease time (record the lease). The movement of the temporary values to their semi-permanent locations is laid out in the DHCP_BIND case of the dhcp_state_engine function. Once the lease values are recorded, Figure 1 shows us that the DHCP code will logically move into the BOUND state. We now have an assigned IP address, a gateway IP address, and a subnet mask value. The ARP and ICMP (PING) functions in our ENC28J60 driver code will now operate using the newly assigned IP address. The TCP Telnet application and the UDP echo application within the ENC28J60 driver code will also respond to the new IP address.

The Frame Thrower II must be equipped with the 32.768 kHz real time clock hardware (32.768 kHz crystal and supporting 20 pF capacitors) to utilize the lease timer interrupt routine in our DHCP code. The Frame Thrower II's RTC (Real Time Clock) is set up to interrupt every second. Since the lease time is given to us in seconds, this works out well. Once we have received and recorded a valid DHCP lease, the DHCP state engine enters the DHCP_BOUND state and every second that passes decrements the lease time value that we were granted. The DHCP lease renew code is set up to attempt to renew the lease 30 minutes before it officially expires. The Frame Thrower II's RTC can also be used as a time-of-day clock and still service the DHCP lease timing function.

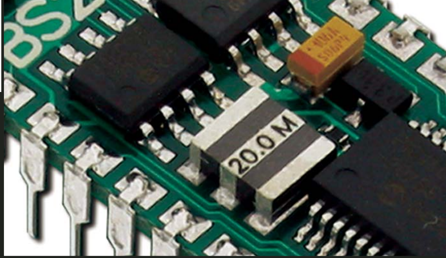
FUN STUFF

The DHCP code we've examined will send status and result messages to the Frame Thrower II's serial port. The serial port settings are easily found within the DHCP download code package. The text messages you see in Photo 1 were created one by one as the DHCP code flowed through each of the DHCP states shown in Figure 1. Once the DHCP offer was processed and accepted, the lease values received by the Frame Thrower II were also sent to the Frame Thrower II's serial port. Note that the Linksys AP (192.168.1.1) leased my Frame Thrower II an IP address of 192.168.1.102. Our ENC28J60 driver code doesn't use the subnet mask or gateway IP address, however, they are there if your application needs them.

Here's a fun way to put that UDP knowledge you gained in an earlier Design Cycle column to use. Our Frame Thrower II DHCP code also includes a routine (send_dhcp_bound_datagram) that sends a UDP datagram containing the same data that is transmitted via the Frame Thrower II's serial port with the addition of the Frame Thrower II's MAC address information when the DHCP code goes into a DHCP_BOUND state. You can receive the UDP datagram by simply running the MCHPDetect program that is included with the free Microchip TCP/IP stack on a PC that is connected to the same network segment that the Frame Thrower II and Linksys AP are using.

The MCHPDetect application listens for UDP messages sent to UDP port 30303. All I had to do was assemble a UDP datagram with my desired message inside an IP datagram and address the UDP datagram to port 30303. The IP datagram is addressed to the broadcast address of 192.168.1.255. The contents of Photo 2 are what you should see when you compile, load, and run the DHCP code I've provided. The IP addresses will vary depending on how your IP addressing is set up within your DHCP server. My Linksys AP is set up to start distributing DHCP leases at IP address 192.168.1.100. My laptop, which runs my Ethernet Sniffer and the MCHPDetect program, took 192.168.1.101.

We started this whole Internet protocol thing by gaining a working knowledge of UDP. Then, we added our knowledge of IP gained in the UDP discussion to get our arms around TCP/IP. Along the way, we learned about ICMP and ARP. Now, using knowledge you gained from Design Cycle about the easiest Internet protocol of them all — UDP — you have added the power of DHCP to your Design Cycle arsenal. **NV**

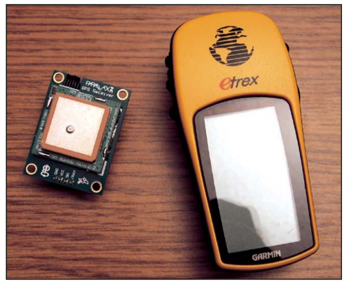


STAMP APPLICATIONS

PUTTING THE SPOTLIGHT ON BASIC STAMP PROJECTS, HINTS & TIPS

■ BY JON WILLIAMS

HACKING THE PARALLAX GPS MODULE

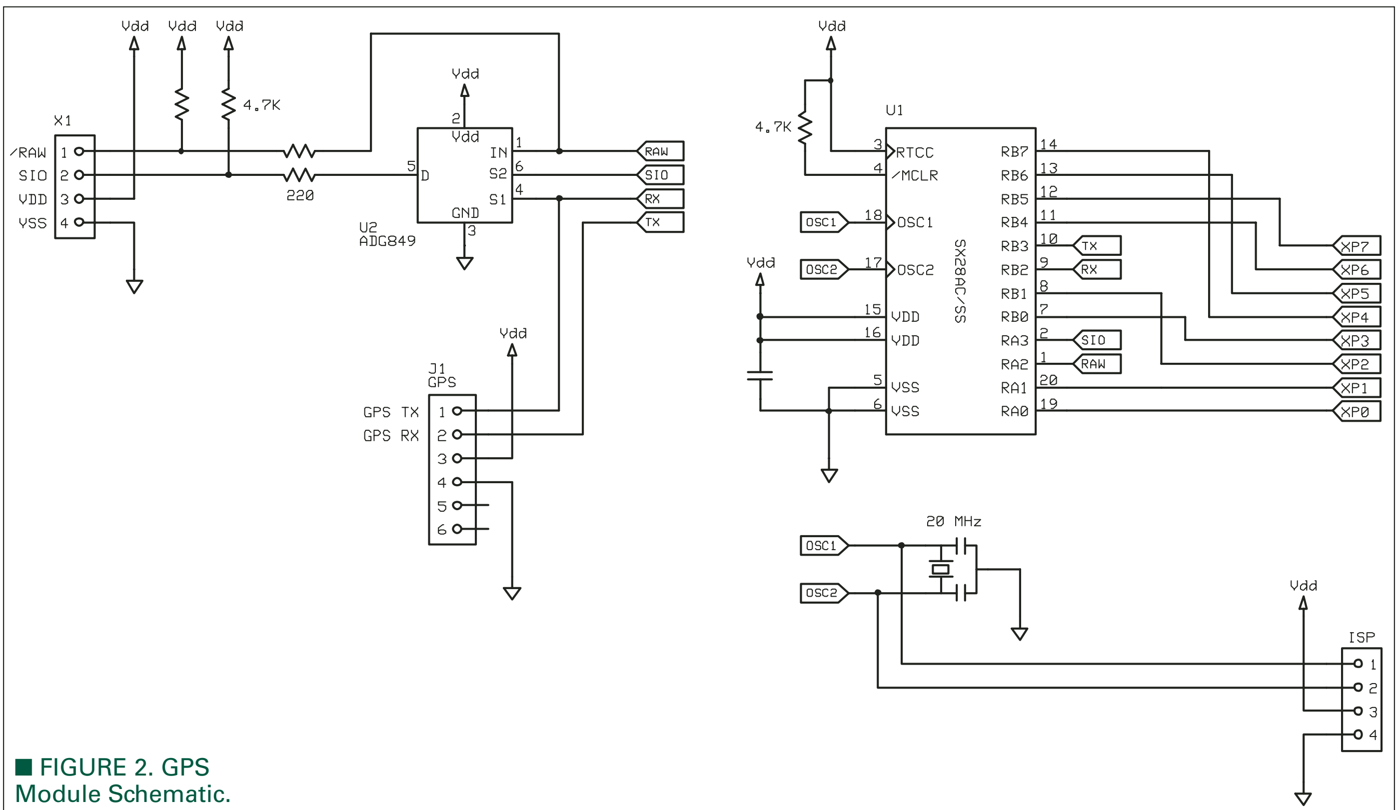


■ FIGURE 1. The GPS Units.

IN SEPTEMBER, WE TALKED ABOUT exciting new updates in the SX/B compiler and now we're going to put a few of them to use with a cool new GPS product from Parallax. This isn't just another GPS module. It was specifically designed to be hacker-friendly. How? Well, it uses an SX20 and the firmware was written in SX/B — and you can download this code from Parallax. Better still, is the addition of several nondescript pads on the PDB; these pads give us access to I/O pins on the SX20, and with a little effort, the ability to reprogram the module with custom firmware.

I've never considered myself much of a hacker, but with the Parallax GPS module I couldn't pass up the opportunity to give it a go — especially since the module is just begging to be hacked! Again, that's by design, and it should come as no surprise that Parallax teamed up with one of the best known hackers in the western world — Joe Grand of Grand Idea Studio.

Many BASIC Stamp users know of Joe through his collaboration with Parallax on the RFID Reader. When Joe happened across a neat little GPS receiver module from Polstar, he showed it to Parallax and a new project was born. GPS is becoming increasingly more available and popular with experimenters, and this is especially true in hobbyist robotics as evidenced by the recent "mini DARPA challenge"

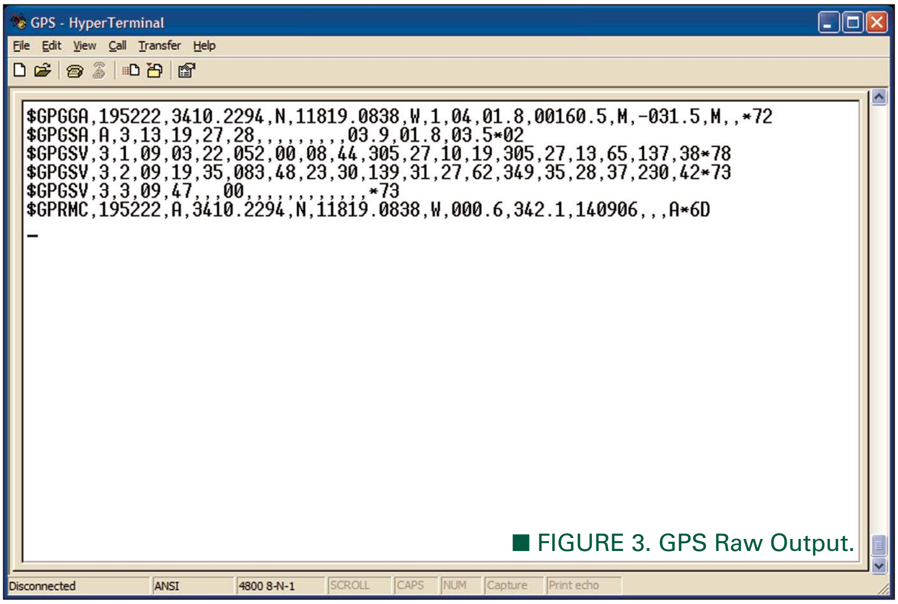


■ FIGURE 2. GPS Module Schematic.

competitions sponsored by robotics clubs. The Parallax GPS module makes things very easy — and the size and form-factor work well, too. Figure 1 shows the Parallax GPS next to a Garmin eTrex unit that we've used in previous experiments.

If you look at the schematic in Figure 2, you'll see that the design is quite neat and tidy. The major components are a Polstar PMB-248 GPS receiver (connected to J1), the SX20, and an analog switch. The insertion of the analog switch is particularly clever on Joe's part; this allows the module to reroute the serial output from the GPS receiver directly to the SIO pin when the RAW pin is pulled low. In normal ("smart") operation, this pin is left to be pulled high and the SX20 processes the GPS data for us.

What I like about the module is that the GPS receiver spits out NMEA strings every second. To test the output, I configured the module for raw mode and fed the SIO pin to HyperTerminal through a MAX232 level shifter. Figure 3 shows the NMEA sentences provided by the Polstar GPS module. Like common GPS modules, the baud rate is 4800.



■ FIGURE 3. GPS Raw Output.

CUSTOM GPS

Okay, why customize the module when it works so well? For me, there were a few reasons. First, it would be fun and educational. Second, I could take advantage of the extra SX20 I/O pins and, finally, I could bump up the communication speed to make it compatible with the Parallax Servo Controller. It seems to me that the GPS module and PSC make a good robotics pair, so making the GPS module more compatible is a good idea. And in the end, even if you don't decide to customize your GPS module, the code we'll develop here can be used for other AppMod-compatible devices.

Some time back, Parallax developed a simple serial communications protocol for its AppMods; devices that connected to the BOE's (Board of Education) AppMod header. The protocol uses Open-True serial mode — this is critical. True mode means that the idle state of the serial line is high, and Open-True means that the idle (0) state is accomplished with a pull-up. When a transmitting device wants to exert a "1" bit, it pulls the line low. This configuration allows several devices to be bussed together without fear of electrical conflicts as the serial line is never driven high.

By tradition, the AppMod protocol starts with a "!" character, followed by a two- or three-character device ID string. The original intent of the "!" character was to allow devices to determine the baud rate of the incoming stream. We're not going to do that here as auto-baud programming can be quite messy, and our goal is to have fun. Since the likely host of the GPS module will be a BS2-type processor, we're going to fix the baud rate to 38.4K; this matches the high-speed mode of the PSC, and allows the host program to have a single baud constant for both devices.

Let's jump in, shall we? After the obligatory definitions, our program starts as follows:

```
Main:
  IF Raw = 0 THEN Main

Wait_For_Header:
  char = RXBYTE
  IF char <> "!" THEN Wait_For_Header
  char = RXBYTE
  IF char <> "G" THEN Wait_For_Header
  char = RXBYTE
  IF char <> "P" THEN Wait_For_Header
  char = RXBYTE
  IF char <> "S" THEN Wait_For_Header

Get_Cmd:
  char = RXBYTE
  IF char = "I" THEN Get_ID
  IF char = "V" THEN Check_Valid
  IF char = "U" THEN Set_Time_Offset
  IF char = "T" THEN Get_Time
  IF char = "L" THEN Get_Lat
  IF char = "O" THEN Get_Long
  IF char = "K" THEN Get_Knots
  IF char = "H" THEN Get_Heading
  IF char = "X" THEN X_Port
  GOTO Main
```

The first thing we need to do is check the start of the Raw input pin (RA.2). This pin is normally pulled high to enable "smart" mode, i.e., intervention by the SX20. When connected to ground, this signal reroutes the GPS output directly to the SIO pin using the analog switch. Since the SX20 is no longer connected to SIO, we simply loop at Main until Raw returns high. Normally, one will select "raw" or "smart" mode via hardware, yet this is a standard input and could be controlled dynamically by the host processor. Just keep in mind that raw mode output is at 4800 baud, and smart mode serial I/O is at 38.4 kb.

Assuming we're in smart mode, the program jumps down to Wait_For_Header where we do just that: we wait on the "!GPS" header that precedes a command or request from the

host. From a PBASIC standpoint, this may look a little clumsy but this is, essentially, how the PBASIC **WAIT** modifier operates. And if you look at the compiled output, you'll see that it uses very little code. Note that we've wrapped the **SERIN** function in the RXBYTE subroutine to conserve program space — this is always a good idea for commands that generate a lot of assembly code, and we'll see more examples of that in our program.

After the proper header has arrived, we pull the next byte from the stream and compare it to a list of valid commands. If there is a match, we will jump to the code that handles that command, otherwise we'll branch back to the top and wait for another header/command sequence. I chose the **IF-THEN** style for this section because I find it easy to update and modify. SX/B now includes an **ON-GOTO** structure that some programmers will find a bit more elegant.

Let's work through a few of the commands — we don't have to go into detail about all of them because you'll see that they take advantage of some core subroutines, and those routines I think you'll find useful in other SX/B programs.

My version of the smart GPS module behaves a little differently than the Parallax program in that it buffers the GPS stream (like we did with the scratchpad RAM in the old BS2p GPS project) and then pulls data from it instead of waiting on a new stream for each command. What this means is that we need to get a valid stream before we ask for any other data, and this is the purpose of the Check_Valid (command = "V") code:

```
Check_Valid:
  GETRMC
  FINDFIELD 1
  char = GETBUF bufPntr
  DELAYMS 15
  TXBYTE char
  GOTO Main
```

What we're going to see is that this little section of code has a whole lotta stuff going on behind it. First things first: We need to receive and buffer the $GPRMC sentence from the receiver, and that is the purpose of the GETRMC subroutine.

```
GETRMC:
  char = GPSRX
  IF char <> "$" THEN GETRMC
  char = GPSRX
  IF char <> "G" THEN GETRMC
  char = GPSRX
  IF char <> "P" THEN GETRMC
  char = GPSRX
  IF char <> "R" THEN GETRMC
  char = GPSRX
  IF char <> "M" THEN GETRMC
  char = GPSRX
  IF char <> "C" THEN GETRMC
  char = GPSRX
  IF char <> "," THEN GETRMC

  FOR bufPntr = 0 TO 63
    char = GPSRX
    PUTBUF bufPntr, char
    IF char = "*" THEN EXIT
  NEXT
  RETURN
```

Note that the top part of this routine works just like the code that waits on the command header, the difference being that we're now getting characters from the GPS receiver at 4800 baud, hence the GPSRX subroutine. Once the front part of the $GPRMC sentence has been received, we will put the rest of the characters (up to the checksum) into a 64-byte buffer.

Wait a minute ... we can only have 16-byte arrays with the SX20, so how do we get a 64-byte buffer? Well, we build it out of four 16-byte arrays and a little code. I originally wrote this buffer code for the Parallax Inkjet module project and have found it quite useful. First, let's look at the variable assignments:

```
bufPntr       VAR    Byte
bufA          VAR    Byte (16)
bufB          VAR    Byte (16)
bufC          VAR    Byte (16)
bufD          VAR    Byte (16)
```

As you can see, we've created four, 16-byte arrays that we'll concatenate with a little code. Let's start with putting a byte into the buffer. This works very much like the BS2p's **PUT** instruction that requires an address and the byte value to write.

```
PUTBUF:
  tmpB1 = __PARAM1
  tmpB2 = __PARAM2
  tmpB3 = tmpB1 & %00111111
  tmpB3 = tmpB3 >> 4
  tmpB4 = tmpB1 & %00001111

  IF tmpB3 = %00 THEN
    bufA(tmpB4) = tmpB2
  ENDIF
  IF tmpB3 = %01 THEN
    bufB(tmpB4) = tmpB2
  ENDIF
  IF tmpB3 = %10 THEN
    bufC(tmpB4) = tmpB2
  ENDIF
  IF tmpB3 = %11 THEN
    bufD(tmpB4) = tmpB2
  ENDIF
  RETURN
```

This routine starts by collecting the buffer address (passed in __PARAM1) and the data byte (passed in __PARAM2) and then creating the array and index pointers for the buffer. The array pointer is derived by shifting the address right four bits (we're extracting the high nibble), and the index within the array comes from the low nibble of the address.

This is a useful technique so let's talk about it. What if we needed a 24-byte buffer? The trick is to keep the array sizes equal, and use an even power of two. For a 24-byte buffer, I would use three eight-byte arrays. This fits neatly within the SX's banked RAM space and allows the techniques used above for addressing, the difference being we'll shift the address right three bits, and use the lower three bits of the address as the index within each array.

Okay, we have the $GPRMC string buffered, but we don't know if the string was valid. There is a character in the string that gives us this information, and it is in the field that follows the time. To locate a field within the string, we can

use the FINDFIELD subroutine. Its purpose is to count commas until the desired position is located (and then store in *bufPntr*).

```
FINDFIELD:
  tmpB5 = __PARAM1

  bufPntr = 0
  IF tmpB5 > 0 THEN
    DO
      char = GETBUF bufPntr
      INC bufPntr
      IF char = "," THEN
        DEC tmpB5
        IF tmpB5 = 0 THEN EXIT
      ENDIF
    LOOP
  ENDIF
  IF bufPntr >= 64 THEN
    bufPntr = 0
  ENDIF
  RETURN
```

For this routine to work, we must pass a field number that is greater than zero. Then we start at the beginning of the buffer, pulling characters from it with GETBUF. For each comma found, the field number is decremented and when we reach zero, we're sitting at the start of the desired field. I put a little error trapping in the code to prevent the pointer from being incremented outside the bounds of the buffer.

Back to Check_Valid (yes, we're still working on that). Now that we're pointing at the validity character in the GPS string, we can pull it and send it back to the host. It's a good idea to insert a short delay (I used 15 milliseconds) before sending anything back to the host. This allows the host to be ready with its **SERIN** instruction. BASIC Stamps don't take that long to set up, but if the host is a Javelin Stamp using one pin for serial input and output, it takes a little extra time.

As you can see, we've done quite a bit of background work to support the commands required for the smart mode of the module — and there's more! One of the useful features of GPS is getting accurate time, so let's explore that as there are support routines used here that will nicely migrate to other applications.

```
Get_Time:
  DELAYMS 15
  result = BUF2DEC 0, 2
  result_LSB = result_LSB + utcOffset
  IF result_LSB > 23 THEN
    result_LSB = result_LSB - 24
  ENDIF
  TXBYTE result_LSB
  result = BUF2DEC 2, 2
  TXBYTE result_LSB
  result = BUF2DEC 4, 2
  TXBYTE result_LSB
```

When we have a valid $GPRMC string, the first six characters indicate the current time as hhmmss. Remember that these are text characters, so we're forced to do a numeric conversion. I created a little subroutine called BUF2DEC to do just that. What this does is let us point to a number within the buffer, specify how wide it is, and get back the decimal value — somewhat analogous to the PBASIC **DEC** modifier when used with **SERIN**.

```
BUF2DEC:
  bufPntr = __PARAM1
  tmpB5 = __PARAM2
  tmpW3 = 0
  IF tmpB5 >= 1 THEN
    IF tmpB5 <= 5 THEN
      DO
        tmpW3 = MULT tmpW3, 10
        tmpB6 = GETBUF bufPntr
        tmpB6 = tmpB6 - "0"
        tmpW3 = tmpW3 + tmpB6
        INC bufPntr
        DEC tmpB5
      LOOP UNTIL tmpB5 = 0
    ENDIF
  ENDIF
  RETURN tmpW3
```

As I stated above, we need to pass the location within the buffer (__PARAM1) and the width of the number (__PARAM2). If the width is legal, then a loop construct iterates through the field width, doing a decimal shift left (multiply by 10) and adding in the next digit.

Multiplication is another instruction that generates a lot of assembly code and it's best to encapsulate within a subroutine to conserve code space. We do that in the MULT code as shown below.

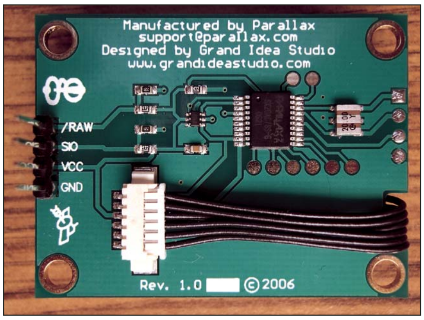
```
MULT:
  IF __PARAMCNT = 2 THEN
    tmpW1 = __PARAM1
    tmpW2 = __PARAM2
  ENDIF
  IF __PARAMCNT = 3 THEN
    tmpW1 = __WPARAM12
    tmpW2 = __PARAM3
  ENDIF
  IF __PARAMCNT = 4 THEN
    tmpW1 = __WPARAM12
    tmpW2 = __WPARAM34
  ENDIF

  tmpW1 = tmpW1 * tmpW2
  RETURN tmpW1
```

Now, there's nothing magic here, but I'm including it to illustrate a clean method for dealing with mixed values. We can determine what got passed to the subroutine via __PARAMCNT. When this has a value of 3, we know that we're mixed. I tend to like to pass Word, then Byte when I used mixed values. Note that the first parameter (the word) is passed by the compiler via __WPARAM12, and the second parameter (the byte) is passed through __PARAM3.

Can you do it the other way, i.e., byte value first? Yes, just change the middle section like this:

```
  IF __PARAMCNT = 3 THEN
    tmpW1 = __PARAM1
    tmpW2 = __WPARAM23
  ENDIF
```



■ FIGURE 4. GPS Module (bottom).

It doesn't matter which you use, just pick a strategy and stick with it so you can port your subroutines from program to program without trouble.

To finish with the time, the local UTC offset is added to the hours and corrected to keep the value 0 to 23. We can send the UTC offset to the module with the "U" command; this lets us get localized time back and not have to deal with that on the host side. The UTC offset is always positive, so to handle a negative offset (as in -8 hours for Hollywood, CA), we will add that value to 24.

As you look through the full listing, you'll see that the majority of the commands work like Get_Time, plucking requested values from the GPS string and sending them back to the host.

REMAPPING BITS

At the top I started by saying the GPS module was hacker-friendly, and it is, but it's not entirely hacker-convenient. The realities of PCB design sometimes get us — and they do with the extra "hacker pins" on the module. Figure 4 shows the bottom of the Parallax GPS module. On the left is the host connection port, the white connector at the lower left goes to the GPS receiver, and you can clearly see the SX20, the hacker pads, and the pads for reprogramming using an SX-Key or SX-Blitz.

There are eight hacker pads and, in an ideal world, these would have been mapped to port RB on the SX20. In the real world, however, they're not. My guess is that this would have complicated the PCB. No problem, we'll "fix it in software" (as a product manager, I always hated hearing that phrase, and I use it only teasingly — nothing is broken).

This "problem" actually gives us an opportunity to explore a bit more of SX/B. In the SX20 and SX28, the data direction (TRIS) registers are not readable, they can only be written. In the BASIC Stamp and in SX/B, this limitation is dealt with by creating shadow registers of the current TRIS states. When we use a command that affects a pin's I/O direction, this register is read, modified, and then written back to the associated TRIS register for that pin. We're going to take advantage of this shadow register to make those eight hacker pins look like one contiguous port.

On receipt of an "X" command to the GPS module, the program jumps to a section that processes one of three secondary commands for the port: "S" for setup (set TRIS), "W" for write bits, and "R" for read bits. Before we get to that, let's look at the individual pin assignments for what I'm calling the *xport*:

```
XP0             PIN     RA.0
XP1             PIN     RA.1
XP2             PIN     RB.1
XP3             PIN     RB.0
XP4             PIN     RB.7
XP5             PIN     RB.6
XP6             PIN     RB.4
XP7             PIN     RB.5
```

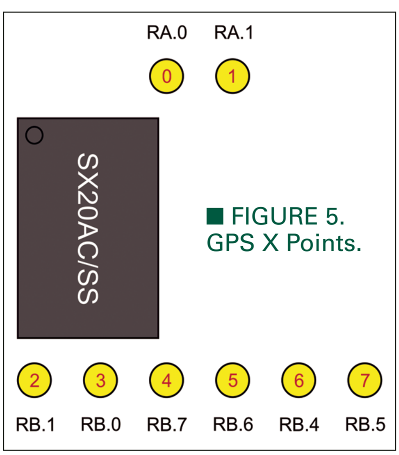
I know from these assignments that it seems the bits are all over the place. Figure 5 shows the remapping of the xport bits — you can see the organization is set up to make things easy to remember.

The "XS" command sequence lets us set up the xport pins like any other SX port, and we will use SX conventions, that is, a 0 bit indicates an output, a 1 bit indicates an input. Here's the code:

```
SETUPXP:
  tmpB1 = __PARAM1
  tmpB2 = TRIS_A
  tmpB2.0 = tmpB1.0
  tmpB2.1 = tmpB1.1
  TRIS_A = tmpB2
  tmpB2 = TRIS_B
  tmpB2.1 = tmpB1.2
  tmpB2.0 = tmpB1.3
  tmpB2.7 = tmpB1.4
  tmpB2.6 = tmpB1.5
  tmpB2.4 = tmpB1.6
  tmpB2.5 = tmpB1.7
  TRIS_B = tmpB2
  RETURN
```

As you can see, there are really two sections to this code: one for each of the SX ports (RA and RB). What we have to do is get a copy of the TRIS shadow register, modify the appropriate bits without touching the others, and then write it back. This is, in fact, what a lot of SX/B functions do when there is a necessary I/O state for an instruction. This method ensures that the port pins not associated with our xport are not adversely affected.

Okay, now that the port bits are set up, the write and read methods are downright trivial.



■ FIGURE 5. GPS X Points.

RESOURCES

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PARALLAX, INC.
www.parallax.com

GRAND IDEA STUDIO
www.grandideastudio.com

```
WRXPORT:
  tmpB1 = __PARAM1
  XP0 = tmpB1.0
  XP1 = tmpB1.1
  XP2 = tmpB1.2
  XP3 = tmpB1.3
  XP4 = tmpB1.4
  XP5 = tmpB1.5
  XP6 = tmpB1.6
  XP7 = tmpB1.7
  RETURN

RDXPORT:
  tmpB1.0 = XP0
  tmpB1.1 = XP1
  tmpB1.2 = XP2
  tmpB1.3 = XP3
  tmpB1.4 = XP4
  tmpB1.5 = XP5
  tmpB1.6 = XP6
  tmpB1.7 = XP7
  RETURN tmpB1
```

Yes, the funky bit mapping forces us to do things a bit at a time, but keep in mind that the SX20 on the module is running at 20 MHz — this is pretty zippy and the transfer of bits happens in about two microseconds.

I think that's about enough fun for this month, don't you? Even if you don't hack the Parallax GPS module, do give it a try as it's small, neat, and works very nicely. Remember, its raw mode output lets us use it like any other GPS, so we can quickly port old programs to it. Until next time, Happy Thanksgiving and Happy Stamping! **NV**

BY L. PAUL VERHAGE

THE BALLOONSAT FLIGHT COMPUTER

LAST YEAR, I WROTE A COLUMN ABOUT MY improvements to the BalloonSat airframe. So this month, I want to discuss my improvements to the avionics.

FIGURE 1. The bottom five modules on this near space stack are student BalloonSats. Above them are two tracking modules and a parachute.

The avionics of a typical BalloonSat is a Hobo H08-002-02 (temperature and one external voltage) data logger and APS camera with timer relay. Hobos are great data loggers and ideal for BalloonSats since they have the weight and volume of a small box of matches. The Hobo series of data loggers are manufactured by OnSet Computing and you can learn more about their wide selection of data loggers from their website at **www.onsetcomp.com**. The only limitation of a Hobo is that it doesn't operate experiments, but this is not a limitation for what the vast majority of BalloonSats students are building.

An APS camera is limited to 40 exposures, but like Hobo, it's nearly bullet-proof. So, an APS camera also works well in BalloonSats. It's the 555 relay timer circuits that leave the most to be desired. Most of them are commercially produced soldering kits that, while reliable, are heavy and require 12 volts to operate.

I call my new BalloonSat avionics the BalloonSat Flight Computer, or BFC. The BFC records data like a Hobo, but it also operates experiments and controls more complex cameras than the traditional BalloonSat avionics.

DESCRIPTION OF THE NEARSYS BALLOONSAT FLIGHT COMPUTER

The BFC has four analog channels, two digital channels, and one kilobyte of memory. It's designed around the BASIC Stamp 1, so it has the capability to operate a BalloonSat while being easy to program.

Analog and digital sensors and experiments are connected to the BFC through receptacles, and each receptacle can supply five volts and ground. This makes building experiments easier because they interface to the BFC with just a three pin male header. The BFC's four analog channels are inputs to an ADC0834 analog-to-digital converter (ADC) and the two digital channels are inputs to the BS-1 (pins P6 and P7). The ADC0834 has the same resolution as the Hobo H08 data logger (256 bits of resolution) but a larger voltage range of five volts (rather then 2.5 volts). That, unfortunately, means the BFC cannot resolve analog volts to the fineness of the Hobo. But for a student BalloonSat, that's acceptable.

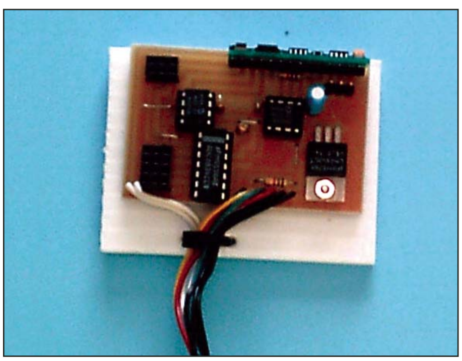
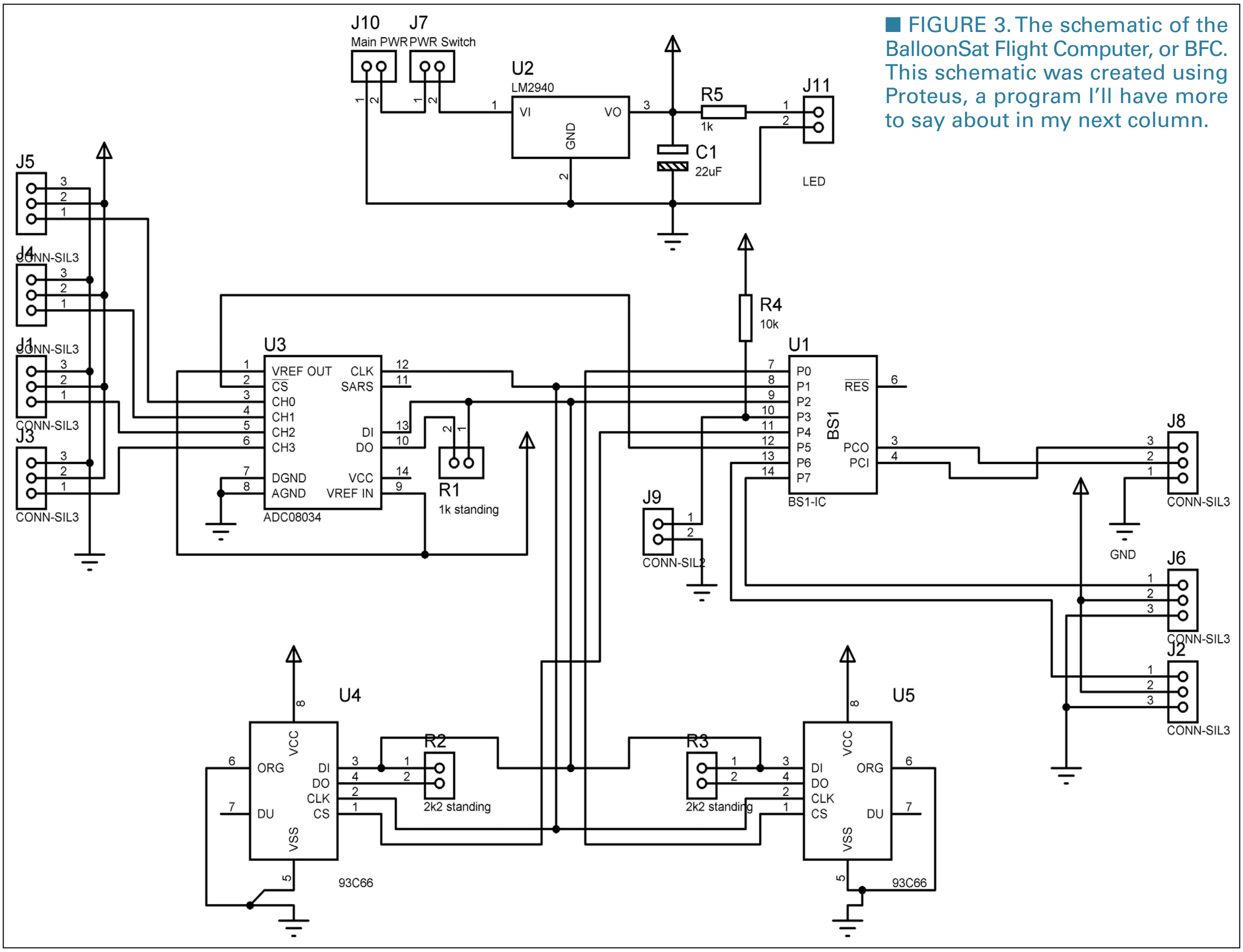


FIGURE 2. The BFC measures 2.5 inches by 1.6 inches.

NOTE: A negative mask of the copper pattern of the BFC is available on the *Nuts & Volts* website at **www.nutsvolts.com**. For readers who don't make their own PCBs, I'll arrange to have the PCB commercially manufactured. Email me for details.

Two Microchip 93C66 EEPROMS (512 bytes each) form the memory of the BFC. The EEPROMS can retain data for 10 years without a battery backup, should your BalloonSat get lost that long. The memory of the BFC isn't nearly as large as the Hobo's (again showing that it's tough to beat a Hobo), but 1,024 bytes of memory is still a lot. That's equal to 1,024 eight-bit measurements of the ADC. On a 2-1/2 hour near space mission, that's enough memory to digitize a sensor voltage every nine seconds. However, since measurements are normally made on all four analog channels at the same time, a complete collection of sensor



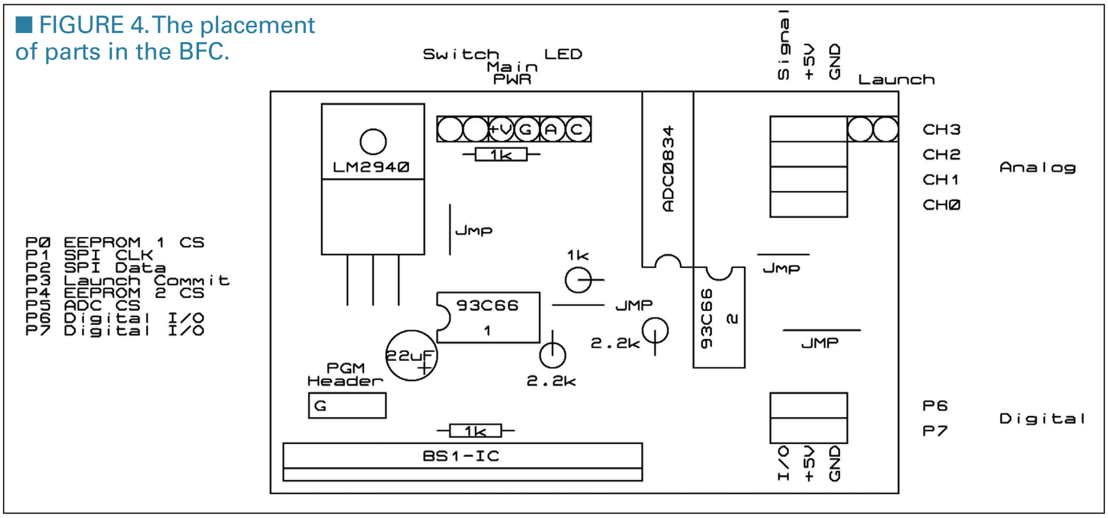
■ FIGURE 3. The schematic of the BalloonSat Flight Computer, or BFC. This schematic was created using Proteus, a program I'll have more to say about in my next column.

data can be made every 35 seconds. At a climb rate of 1,200 feet per minute to an altitude of 85,000 feet (typical of near space missions), data can be collected every 550 feet during ascent and 1,100 feet (on average) during descent.

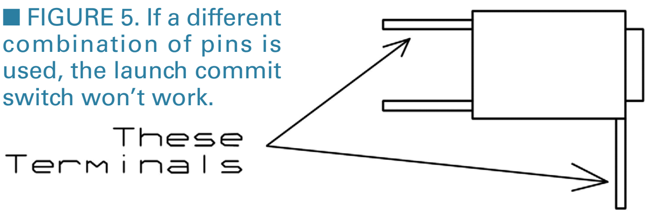
The BFC uses a LM2940T-5 for a voltage regulator. Therefore, the maximum current the BFC can supply is one amp. Since BalloonSat experiments usually don't draw a lot of current, four AAA cells (six volts) is sufficient to operate a BalloonSat for several missions. Connecting to the BFC are cables for its battery pack, a main power switch, a power indicator LED, and a mission initiate pin.

SOLDERING THE BFC

Start assembling the BFC printed circuit board (PCB) by soldering the lowest lying components first, like the flat lying resistors. Use the cut resistor leads for the PCB's four jumpers. To protect the ICs from heat damage, use IC sockets instead of soldering the ICs directly to the PCB. Rather than



■ FIGURE 4. The placement of parts in the BFC.



■ FIGURE 5. If a different combination of pins is used, the launch commit switch won't work.

■ FIGURE 6

purchasing a 14-pin, single row receptacle for the BS-1, cut a less expensive 28 pin dip socket in half lengthwise (to make a single row of 14 pins) and solder one side of the IC socket to the PCB. The digital and analog channels are female receptacles and the BS-1 programming header is a right angle male header. Note that there are three resistors standing on end in the center of the PCB.

THE BFC CABLES

There are four cables (each cable is a pair of wires) attached to the BFC. The cables are soldered to the PCB at its top, as shown in Figure 4. The connection pads for the cable wires are labeled Switch, Main PWR, LED, and Launch. The length of the cables depends on the BalloonSat's dimension, but I've found making them six inches long works well. But if the BalloonSat is large, then cut the wires for the cables longer (you can always wrap up any excessive length).

Both the BFC Main PWR cable and its battery pack are terminated with a Deans Micro Plug. Using micro plugs instead of permanently soldering the battery pack to the BFC makes it easier to install the BFC into a BalloonSat because the battery pack isn't hanging off of it.

A four "AAA" cell holder is ideal for the BalloonSat's battery pack. The cable for Switch terminates with a micro-miniature toggle SPST switch. Don't forget to slide heat shrink tubing over its wires before soldering them to the switch. I recommend covering the back end of the toggle switch with a dab of hot glue to further protect the soldered connection. The LED cable terminates in what else, an LED. Just like the toggle switch, slide heat shrink tubing over the LED wires before soldering the LED leads. Again, cover the back end of the LED with a little hot glue.

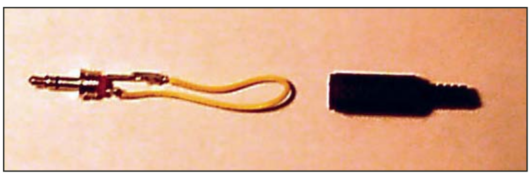
The Launch cable is the launch commit switch and it's a great addition to BalloonSats (and to traditional near spacecraft also). The launch commit switch is essentially a SPST switch with a 1K pull-up resistor. But instead of using a traditional switch, it uses a female phono receptacle and matching shorted phono jack.

When the shorted phono jack is inserted into the phono receptacle, the BS-1 pin P3 shorts to ground and the BS-1 program remains in a loop. When the phono jack is removed, P3 goes high and the BS-1 starts its mission program. So, the launch commit lets students power up their BalloonSat while the balloon is filled without logging data until it's time to launch.

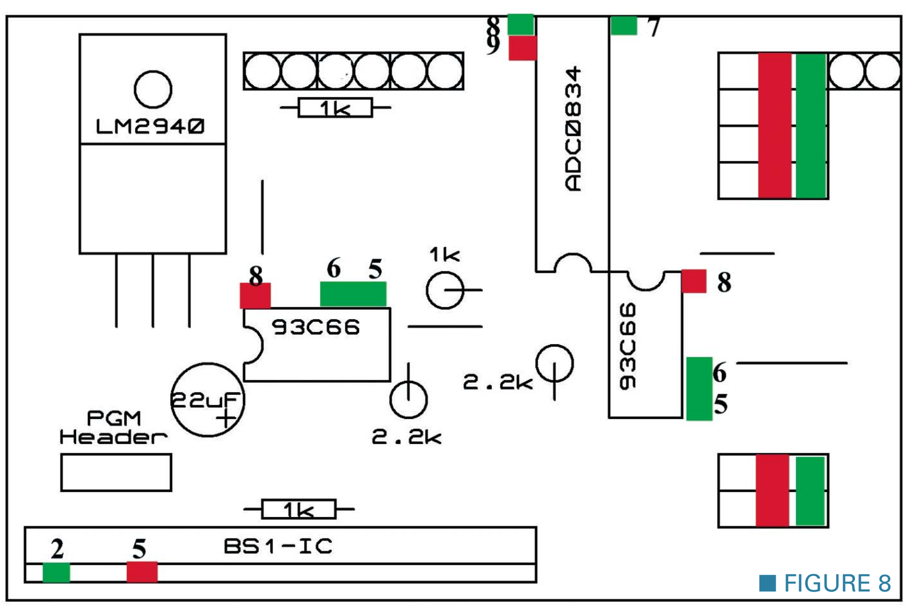
To keep it small, use a 3/32 inch (or 2.5 mm) phono jack and receptacle for the launch commit switch. The Launch cable wires attach to the phono jack receptacle, as illustrated in Figure 5.

To make the male portion of the launch commit switch, unscrew the phono jack's plastic cover and solder a six inch length of wire between the tip and base tabs. Fold the wire sharply in half and test that the phono jack tip and base are shorted with a multimeter.

Next, pass the jack's folded wire through the opening in the back of the phono jack cover and screw the cover



■ FIGURE 7. Notice that the shorting wire is long enough to form a loop that will extend beyond the phono jack's plastic cover.



■ FIGURE 8

BALLOONSAT 101

In case you haven't read my columns about BalloonSats, they're simplified versions of near spacecraft that traditionally carry only data loggers and cameras. BalloonSats don't have complex tracking equipment. This simplifies their construction, but makes them dependent on a traditional near spacecraft for their flight into near space. You can think of BalloonSats as stand-alone payloads for near spacecraft.

back on. Fill the interior of the plug cover with hot glue. Complete it by tying a Remove Before Flight tag to the loop of wire sticking out the back of the phono jack. With a big bright ribbon, students won't forget to remove it before launch. That or they'll realize they forgot to pull the tag as they watch their BalloonSat sail off (see Figure 6).

FINISHING THE BFC

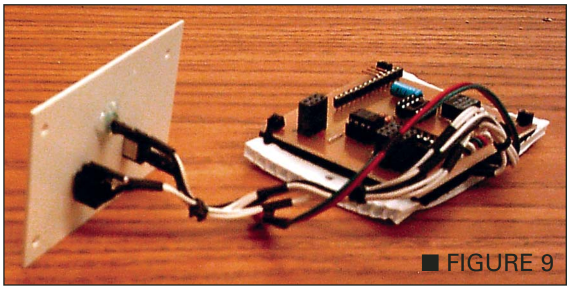
Before plugging the ICs into their sockets, check the back of the PCB for shorts. Then plug the battery pack into the PCB and throw the power switch. The LED should light up. Measure the PCB's voltages. In Figure 8, I've marked the pins that will be +5 volts in red and the pins that will be ground in green. Be sure to disconnect power before installing the ICs into their sockets.

Next, paint colored dots on the BFC to indicate the function of pins in the analog and digital channels. I do this by placing a red dot on the PCB next to a +5V pin and a green paint dot next to a ground pin. A tooth pick and modeling paint are ideal for making the marks.

Mount the BFC to a small sheet of Correplast with double-stick tape and zip-tie the base of all four cables to the Correplast. The zip tie acts like a strain relief and will prevent the cables from being pulled out of the PCB. For added strength, zip-tie the cables together to form a harness. For readers who are not familiar with Correplast, it's a corrugated plastic sheet that's often used to make the cheap signs you see along the road side. Correplast is a lightweight material and very easy to work with.

THE BFC CONTROL PANEL

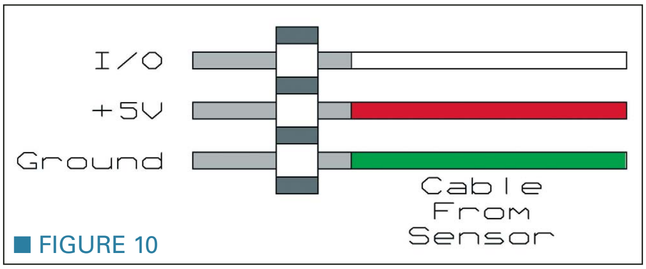
In a completed BalloonSat, the power switch, power indicator LED, and launch commit receptacle are mounted to the BalloonSat airframe. But Styrofoam isn't very durable, so mount them first to a panel of either thin modeling plywood or styrene plastic. The panel is then bolted to the interior side of the BalloonSat airframe. By attaching the panel to the interior side of the airframe, rather than the exterior, the power switch is recessed and protected from accidentally being shut off by a careless bump. So, cut a square or rectangular hole into the airframe large enough for the switch, LED, and phono receptacle, but smaller than the panel they're mounted to. Reinforce the opening in the airframe with a narrow plastic ring on the exterior side of the BalloonSat. Besides, the plastic ring is a more solid mounting surface than Styrofoam. Use small hardware, like #2-56, to bolt the panel to the airframe.



■ FIGURE 9

USING THE BALLOONSAT FLIGHT COMPUTER

Experiments for the BFC must have a three wire cable for I/O, +5V, and ground that terminates in a three pin male header. To make the cable, slide thin heat shrink over the three wires, bare their ends, and tin them. Tin the short side of a three pin male header and solder the ends of the tinned wires to it. Pay attention to the order in which the wires are soldered to the header. One end pin is I/O, the middle pin is +5V, and the pin at the other end is ground (just like a servo). To indicate the proper orientation of the header, I recommend making the wire soldered to the ground pin either a black or green colored wire. Once the solder cools, slide the heat shrink tubing over the pins and shrink them down. The heat shrink protects sensors against shorts in and between the headers.



■ FIGURE 10

The code I used on my last BalloonSat mission is available on the *Nuts & Volts* website (**www.nutsvolts.com**) named "balloonsat.txt." In this flight code, the BFC is programmed to digitize the outputs of four sensors, two temperatures, pressure, and relative humidity (with a miniature weather

NEAR SPACE VIDEOS AVAILABLE ONLINE

After hearing about the popularity of **www.youtube.com** on NPR this summer, I decided to experiment with video production. Currently, I'm using Microsoft Movie Maker (a program that comes packaged with Windows XP) to make short videos about my near space flights this year. The videos incorporate images taken from the ground and from near space. I also added video files recorded in near space and charts made from the data collected by my near spacecraft. Do you want to watch a bag of potato chips burst at 15,000 feet? How about watching a weather balloon burst at 88,000 feet? I won't tell you which ones contain these scenes, so you'll have to watch all of my (short) videos.

I found MS Movie Maker easy to use. I begin by importing the still and video images I want to put into a movie, along with any audio or music. Then I drop the audio and video clips into the time line and set the lengths of time that they will play. After the timings look right, I insert my transitions between images and add the titles and the audio sound track (including copyright free music). It's so neat that I'm thinking of having my students make short educational videos this year.

As I write this month's column, I have seven videos that you can watch over your Internet browser. Go to **www.youtube.com** and search on the terms NEAR SPACE. My videos are named after their flight designation, so they'll be named NearSys 06A, NearSys 06B, etc. When you get a chance, watch my videos and tell me what you think.

station I'll describe in my next column). The results are stored once per minute in the BFC memory for later retrieval. The digital channels switch on the camera, take a picture, and then shut off the camera. This was necessary because the camera has an automatic shut-off feature. It's my contention that the automatic shut-off built into cameras these days is a design fault and not a feature (as if I can't determine for myself when to shut off a camera).

Note that the digital channels are not limited to cameras. There are several types of sensors that output a digital signal rather than an analog voltage that can use the digital channels. Even servos can be operated through the digital channels. As far as I know, no BalloonSat has ever actively participated in its mission by making something happen, they've only passively recorded data. Adding a servo to a BalloonSat can change that.

After recovering my BalloonSat, I needed to download its data (also available on the *Nuts & Volts* website, named "download.txt"). I use a terminal program and a downloading cable to retrieve the data. In place of the terminal program and cable, you should be able to use Stamp Plot Lite and a BS-1 programming cable. However, I didn't have time to test Stamp Plot Lite in time for this column, so I'll have to give you a report on it next time.

Note that there's one variable to change in the download code: the variable NoADC (number of ADC channels used to collect sensor data). This variable formats the data downloaded into the text file. I made my download cable with a three pin male header, two wires, a female DB-9 connector, a DB-9 housing, thin heat shrink, and some hot glue (next to duct tape, hot glue is the most important item in near space!). Cut and strip the ends of two lengths of wire and slide one piece of heat shrink over each wire. Use one wire to connect the ground pin of the male header to pin 5 of the DB-9. Use the second wire to connect the I/O pin of the male header to pin 2 of the DB-9. You'll have two wires soldered to the two outside pins of a three pin header. Use a black wire to distinguish the ground pin of the header from the I/O pin and there'll be less of a chance of plugging the header into the BFC backwards.

After soldering the connections, cover the pins of the male header with heat shrink. Then begin filling the bottom half of a DB-9 housing with hot glue and place the soldered DB-9 connector into the shell. Put some more hot glue into the other half of the DB-9 shell and close the shell halves. Bolt the two halves together and back-fill the opening of the housing (where the cable exits the housing) with more hot glue.

To use the cable, plug the male header of the download cable into an open digital port (either P6 or P7) and program the BFC to download its data (in the downloading code above, data is downloaded over P7). So that there's time to switch the serial cable from programming the BFC to down-

TRANSISTOR EXPERIMENT WINNER

Earlier this summer, I asked readers to look at a transistor experiment I had run while trying to find the minimum amount of current I needed to saturate a transistor. I received a few replies to my request and I've printed Mr. Tom Patrick's response here. Tom, I'm sending you a patch that was sent into near space. Thanks for responding.

Your article in the July '06 *Nuts & Volts Magazine* (and experiment with measuring on-resistance) provide an interesting question for your readers. Your data, so nicely graphed, also illustrate a point of transistor usage which may have been partly lost due to the passing of time and development of newer devices for switching purposes.

To answer your questions, consider the following:

The ohmmeter cannot directly measure resistance. It must use Ohm's law with voltages and currents, and provide an answer based on R = V/I. In other words, the ohmmeter provides a known current, and measures the voltage developed as the current passes through the resistor. The voltage is proportional to resistance (V = I*R), so the measured voltage reading is converted to resistance if the current is fixed.

When you turn on the base-to-emitter junction, you create the possibility of passing electrons from the emitter to the collector, in normal usage of the NPN transistor. The barrier to electron flow is removed, and there is no reason to expect that you could not also pass them backwards, which is what you do when you set up the meter with reverse polarity leads. Nothing says that you cannot use the transistor in an Inverted mode, since you can read "NPN" the same way, forwards or backwards! This point is not made in most semiconductor theory books, because it has not occurred to most technical people to even consider the situation.

The resistance curves are probably correct. You have demonstrated a phenomenon which was exploited in the early days of transistor usage. Someone saw the same thing you saw, and added a bit of insight, in that this was a common connection for use in precision analog switches. With transistor switches biased in the normal manner, the Vce saturation voltages were typically 100 mV, they varied with temperature, and caused great errors in circuits which needed to switch small voltages. With the transistor operated in the reverse direction, the Vce saturation voltage was an order of magnitude lower, allowing the switch to be more accurate.

The first operational amplifiers were made with discrete components. A common configuration for best accuracy (initially with vacuum tubes) is a circuit which converts a DC signal into an AC signal by chopping it up with a switch, then amplifies the AC signal to the desired voltage level. Finally, a second switch, synchronized to the first one, puts the signal back together. This synchronous modulator-demodulator provided better stability, back when a hot transistor had a beta of 20 to 50, and manufacturing processes could not guarantee repeatability between components.

To summarize, the inverted connection is a circuit which had its time in the sun, and is not used any more (or is it?). The physics of transistors can be explored in more detail to understand why the inverted connection has lower on-resistance, but with the advent of D-MOSFETs, and the newer MESFETs, the on resistance is so low that this circuit has mostly been retired.

Sorry that this is so long-winded. Thanks again, for an interesting article.

— Tom Patrick

loading its data, the program waits for the Launch Commit pin to be pulled. So, after programming the BFC to download data, switch the serial cable, and start a terminal program (I use Tera Terminal to download data).

Tera Terminal is a free communications program available over the Internet at **hp.vector.co.jp/authors/VA002416/teraterm.html**. Before starting Tera Terminal, you'll need a text file to save the data. So, create a near space directory with subdirectories for each of your missions. Use Notepad to write the name of the mission into a new text document and save the file in its mission directory. When you start Tera Terminal, you'll need to make these changes to the program's default settings. First, after starting Tera Terminal, a pop-up screen asks for information about the connection it will use. Select Serial Port and click on the com port you'll download data over. Click on the OK button. Next, click on SETUP at the top of the program. In the drop down menu, select SERIAL PORT and select a Baud Rate of 2400. Click the OK button to close. Next click FILE and then click Log in the drop down menu. Navigate to the text file you want to save the downloaded data into. Don't check the Append option. Close the window and get ready to download the data.

Now, pull the Launch Commit pin out and watch the data as it downloads. At the end of the recorded data, click on FILE and then click on Disconnect. This closes the text file your data has been saved in. You'll still have to edit the downloaded data slightly because either Tera Terminal or Notepad (I don't know which yet) is ignoring some of the formatting commands in the downloading code. But since the file contains a maximum of 1 kb of data, the editing goes pretty fast. The resulting file is comma delimited and can be imported directly into Excel for processing.

In the text file, each sensor value is separated by a comma and there's a carriage return (CR) and Line Feed (LF) after each block of data. So, for example, if the BFC recorded data from three sensors, NoADC is set to 3 and the downloaded data should be formatted like this.

```
Rec, ADC-0, ADC-1, ADC-2, ADC-3
1, 124,89,250
2, 123,90,250
3, 122,91,250
```

But, as I said, you'll still have to edit the file slightly to whip it into shape.

By using the programs in this month's column, you can test your BFC's ADC and EEPROM by connecting some of the analog channels to ground and the others to +5V with a 10K resistor. You must use a resistor to do this, if you short the ADC inputs with a wire, you'll damage the ADC.

Well, that's it for this month. Next time, I'll have more on BalloonSats and my experiments with PongSats. You can begin reading about PongSats at the JP Aerospace website at **www.jpaerospace.com**.

Onwards and Upwards,
Your Near Space Guide **NV**

Selected Titles for the Electronics Hobbyist and Technician

The Nuts & Volts Hobbyist BOOKSTORE

ELECTRONICS

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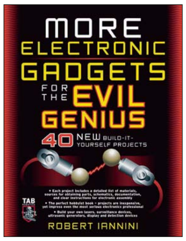

This much anticipated follow-up to the wildly popular cultclassic *Electronic Gadgets for the Evil Genius* gives basement experimenters 40 all-new projects to tinker with. Following the tried-and-true Evil Genius Series format, each project includes a detailed list of materials, sources for parts, schematics, documentation, and lots of clear, well-illustrated instructions for easy assembly. Readers will also get a quick briefing on mathematical theory and a simple explanation of operation along with enjoyable descriptions of key electronics topics. **$24.95**

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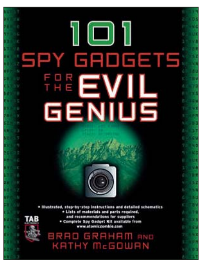

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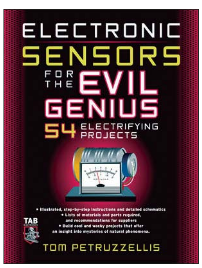

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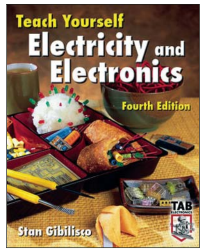
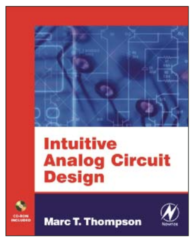


Learn the hows and whys behind basic electricity, electronics, and communications without formal training. The best combination self-teaching guide, home reference, and classroom text on electricity and electronics has been updated to deliver the latest advances. Great for preparing for amateur and commercial licensing exams, this guide has been prized by thousands of students and professionals for its uniquely thorough coverage ranging from DC and AC concepts to semiconductors and integrated circuits. **$34.95**

Intuitive Analog Circuit Design
by Marc Thompson



This book gives readers an intuitive "feel" for analog circuit operation and rules-of-thumb for their design. The author uses analogies from digital design to help readers whose main background is in digital make the transition to analog design. The application of some simple rules-of-thumb and design techniques is the first step in developing an intuitive understanding of the behavior of complex electrical systems. This book outlines some ways of thinking about analog circuits and systems that hopefully develops such "circuit intuition" and a "feel" for what a good, working analog circuit design should be. **$59.99**

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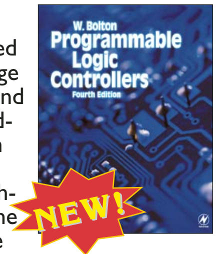
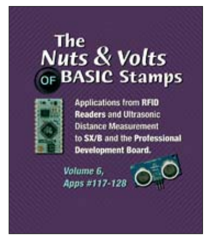


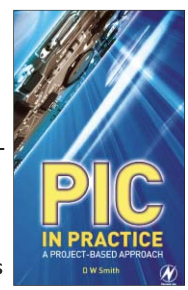
Now in its fourth edition, this best-selling text has been expanded with increased coverage of industrial systems and PLCs and more consideration has been given to IEC 1131-3 and all the programming methods in the standard. The new edition brings the book fully up to date with the current developments in PLCs, describing new and important applications such as PLC use in communications (e.g., Ethernet — an extremely popular system), and safety — in particular proprietary emergency stop relays (now appearing in practically every PLC based system). **$34.95**

Nuts & Volts of BASIC Stamps — Volume #6
by Jon Williams



Nuts & Volts of BASIC Stamps — Volume 6 includes articles #117-128, written for 2005. Article topics consist of RFID Readers and Ultrasonic Measurement, SX/B and the Professional Development Board, the advanced MIDI receiver, programming the SX microcontroller in BASIC, mastering the MC14489 display driver, and more! The Nuts & Volts of BASIC Stamps books are a favorite Parallax technical pick and are a tremendous technical resource for all PBASIC programming projects. **$14.95**

PIC in Practice
A Project-based Approach
Second Edition
by David W. Smith



PIC in Practice is a graded course based around the practical use of the PIC microcontroller through project work. Principles are introduced gradually, through hands-on experience, enabling students to develop their understanding at their own pace. The book can be used at a variety of levels and the carefully graded projects make it ideal for colleges, schools, and universities. Newcomers to the PIC will find it a painless introduction, whilst electronics hobbyists will enjoy the practical nature of this first course in microcontrollers. **$29.95**

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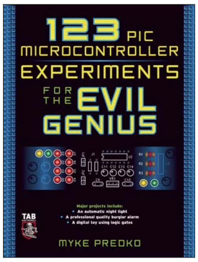
123 PIC Microcontroller Experiments for the Evil Genius
by Myke Predko



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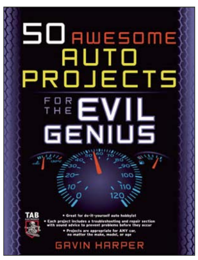
AUTOMOTIVE

50 Awesome Auto Projects for the Evil Genius
by Gavin D J Harper



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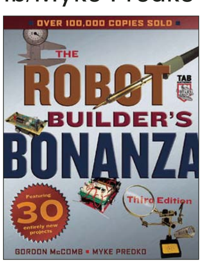
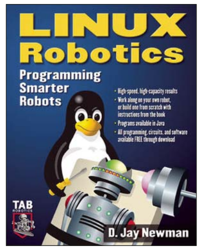
ROBOTICS

Robot Builder's Bonanza Third Edition
by Gordon McComb/Myke Predko



Everybody's favorite amateur robotics book is bolder and better than ever — and now features the field's "grand master" Myke Predko as the new author! Author duo McComb and Predko bring their expertise to this fully-illustrated robotics "bible" to enhance the already incomparable content on how to build — and have a universe of fun — with robots. Projects vary in complexity so everyone from novices to advanced hobbyists will find something of interest. Among the many editions, this book features 30 completely new projects! **$27.95**

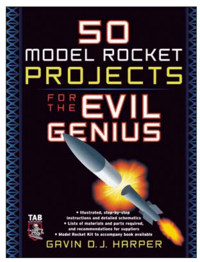
Linux Robotics
by D. Jay Newman



If you want your robot to have more brains than microcontrollers can deliver — if you want a truly intelligent, high-capability robot — everything you need is right here. *Linux Robotics* gives you step-by-step directions for "Zeppo," a super-smart, single-board-powered robot that can be built by any hobbyist. You also get complete instructions for incorporating Linux single boards into your own unique robotic designs. No programming experience is required. This book includes access to all the downloadable programs you need, plus complete training in doing original programming. **$34.95**

PROJECTS

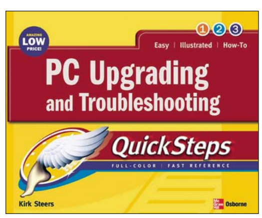
50 Model Rocket Projects for the Evil Genius
by Gavin D J Harper



The fun, hands-on way to learn about rocket science. Yes, as a matter of fact, is IS rocket science! And because this book is written for the popular Evil Genius format, it means you can learn about this fascinating and growing hobby while having fun creating 50 great projects. You will find a detailed list of materials, sources for parts, schematics, and lots of clear, well-illustrated instructions. **$24.95**

HOME COMPUTING

PC Upgrading and Troubleshooting QuickSteps
by Kirk Steers



This low-priced, fast reference uses color screenshots and brief instructions to show and explain how to fix all kinds of PC problems. Each chapter's "How to" list and color coded tabs make it easy to flip straight to specific tasks, such as routine maintenance, start-up issues, drive, monitor, and peripheral problems, Internet connections, upgrading, and more. Useful tips, reminders, shortcuts, and cautions are displayed in the margins so they don't break the flow of the book. **$16.99**

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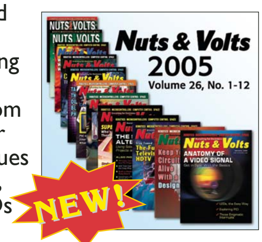
Are you ready for some good news? Along with the first 14 issues of *SERVO Magazine*, all issues from the 2005 calendar year are now available, as well. These CDs include all of Volume 1, issues 11-12, Volume 2, issues 1-12, and Volume 3, issues 1-12, for a total of 26 issues all together. These CD-ROMs are PC and Mac compatible. They require Adobe Acrobat Reader version 6 or above. Adobe Acrobat Reader version 7 is included on the discs. **$24.95 – Buy 2 or more at $19.95 each**

Nuts & Volts CD-Rom



Here's some good news for *Nuts & Volts* readers! Along with all 12 issues of *Nuts & Volts* from the 2004 calendar year, the 2005 issues are now available, as well. These CDs include all of Volumes 25 and 26, issues 1-12, for a total of 24 issues (12 on each CD). These CD-ROMs are PC and Mac compatible. They require Adobe Acrobat Reader version 6 or above. Adobe Acrobat Reader version 7 is included on the discs. **$24.95 – Buy 2 or more at $19.95 each**

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Continued from Page 65

In addition, I would also like to send streaming video from the bot back to the browser using a standard web-cam. Any ideas?

#11062 **Don Peterson**
Pleasanton, CA

Car computers are becoming more and more popular. It seems that the one common thing not available is a good USB AM-FM stereo tuner, which is necessary to rid the car of the in-dash radio and have space to put the computer's screen. I have tried several of the commercially available USB tuners (Radioshark, D-Link, Hauppage). All of them seem to suffer from the same poor sensitivity, especially when used in the automobile environment.

Has anyone built a high quality AM-FM stereo USB tuner, or know of a magazine dedicated to car computers?

#11063 **Dave Delman**
via email

I have a new ICOM IC-R1500 wideband receiver and was wondering if, or how, I could listen to raw GPS data? I have scanned the L1 frequency of 1559.4610 MHz, but all I hear is noise. Likewise result on the L2 frequency of 1227.60 MHz. I would assume that I could at least hear a burst of data once per second?

My antenna is a roof-mounted AOR DS3000A 75 MHz to 3,000 MHz wideband discone. Perhaps I need an antenna specifically tuned to a frequency of 1,560 MHz and possibly a high-gain amplifier, to boot?

#11064 **Phil Blake**
via email

>>> ANSWERS

[#9063 - September 2006]

I have a question about heat dissipation vs. duty cycle. Power increases proportional to current squared, and linearly with respect to resistance. As duty cycle varies, should I use the square root of the on (off?) time to calculate power? (Is this not analogous to pulsed laser calculations where energy is related to pulse duration and can get quite high for short on times?)

#1 Power is proportional to current squared at a given resistance. Power increases linearly with respect to resistance at a given current. In any event, power is directly proportional to the duty cycle ("on" time divided by total time). So, compute the power from P = I squared R or P = I E, and then multiply by the duty cycle. Never take the square root of the "on" time or of the duty cycle. The heat dissipation, of course, is equal to the power.

John Herro
Cincinnati, OH

#2 Average power dissipation is simply duty cycle x power.

In other words, if the load dissipates 100W when on, it will dissipate 10W when the duty cycle is one second on, nine seconds off (10% duty cycle). Note that there are other factors to consider. There is usually a maximum instantaneous power dissipation that cannot be exceeded without damaging the load. Also, the repetition rate must be fast enough that the load doesn't overheat during the on time (the load must have enough heatsinking capability).

Robert Zusman
Scottsdale, AZ

[#10062 - October 2006]

I am a relative newcomer in the world of electronics (especially digital). I have enjoyed reading Nuts & Volts magazine, though there are many questions that go along with the reading. Could someone please explain why all electronic schematics require ground and what exactly ground means?

I would also appreciate a book recommendation for beginners on how to read a schematic diagram. I built a simple transistor radio a while ago, so I am more or less familiar with how the individual basic components work.

A circuit ground is the point or points in a circuit where the voltage at one point is always measured in reference to that point. If measuring 12 volts at a certain point in a circuit, we mean that that point is 12 volts more than the reference point. This reference point is called the ground.

The ground point or reference point is where all of the common points in the circuit are connected to and that go back to the negative side of the source voltage (such as a battery or power supply). Some texts will refer to this reference point/ ground point as chassis ground since the metal chassis of the device serves as the common point where all of the circuit current paths return to.

Thus, we can say that the ground point is the zero volt reference point(s) in an electronic circuit and that this point has a potential or voltage of zero volts and this is with respect to all of the other points in that circuit that are referenced to it.

Now in some circuit descriptions, you might see references to AC ground which differs from the description of the DC ground above. The AC ground is done using a bypass capacitor. This type of ground only exists at high frequencies; at lower frequencies approaching DC or steady state, the capacitor acts as an open and no current will flow to the ground or reference point, but at high frequencies will ground the point in the circuit.

As for your question on schematic reading, check out the sites listed below. One is a very good beginners book on reading schematics and the others are websites that explain how to read schematics.

www.amazon.com/Beginner-s-Guide-Reading-Schematics/dp/0830676325

www.guitarnuts.com/wiring/schematics.php

www.siteswithstyle.com/VoltSecond/Schematic_notes/Schematic_reading_notes.html

www.mitedu.freeserve.co.uk/Prac/prac.html

www.best-microcontroller-projects.com/how-to-read-schematics.html

Ralph J. Kurtz
Old Forge, PA

[#10063 - October 2006]

Has anyone used or reviewed the Cold Heat gadget that one sees advertised on TV, as it pertains to

the electronics hobbyist, especially an absolute beginner like myself?

#1 I bought one of the Cold Heat soldering tools and returned it days later. It does work but it is very touchy. You have to get the tip just right on the joint for it to heat up and most of the time you do have to put some pressure on it which is a problem because the instruction book specifically says do not press down on the tip or you'll break it. It sucks batteries way too fast. This device is only good to keep in a glove box for any emergency solder needs, that way the batteries have a chance to recover a bit from its last use. The thing doesn't heat and cool as fast as it says. It heats up in a short time (20 secs) but the longer it's on, the longer it takes to cool. It normally takes awhile to heat up, so by the time you solder your joint, the thing is too hot to touch or set down for the next minute ... not seconds. The thing does put off sparks when you first touch a solder joint. Melting an already existing solder joint is a lot easier than making a new one. When trying to make a new joint, if you start the tool on the solder pad, you will turn the pad red hot and melt it off the board. If you start it on the solder, the solder starts to melt and you lose the connection between the tips and it stops heating. If you get clumsy with the tip and it touches two pads at once, you will send a bad amount of current through your circuit. My suggestion — save your money.

Kevin Harris
MO

#2 If you check the website of the company, they have two types of Cold Heat tools. The site is:

www.coldheat.com/

Now I have used the Classic version before, the Pro appears to be relatively new. However, for basic soldering projects, the Classic is okay and performed as expected. For basic repairs and small wiring jobs, it will suffice. However, the Pro version is for more serious soldering jobs.

Ralph J. Kurtz
Old Forge, PA

[#10065 - October 2006]

I have a battery charger that had what appears to be red cardboard between the bottom side of the printed circuit board and the case. What is its purpose? Is this just cardboard or some special insulating material?

The "cardboard" is an insulator that will prevent the printed circuit side of the charging circuit from shorting out to the case. Since the case is at zero volts and is common to the ground, you don't want any of the voltage points from the charging circuit to short out to the case. The cardboard is probably what is called Fish Paper or Vulcanized Fiber. It is a strong paperboard insulation used because it is a very good insulator and very flexible. It is much stronger than standard cardboard, and as such, could withstand being in contact with the solder side of a PCB where cardboard might be pierced by the "tails" from the components on the PCB side.

Ralph J. Kurtz
Old Forge, PA


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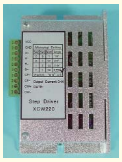

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CW220	99mm x 65mm x 30mm	1/2(400), 1/8(1600)	$49.95
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SONY Super HAD CCD Color Weatherproof IR Cameras

- Day & Night Auto Switch
- Signal System: NTSC
- Image Sensor:1/3" SONY Super HAD CCD
- Horizontal Resolution: 480TV lines
- Min. Illumination: 0Lux

480 TV Lines Resolution

Item# VC-827D: **$132.00**

SONY Super HAD CCD™ equipped camera's feature dramatically improved light sensitivity

Intelligent DMM w/ RS-232

- 3999 Counts and 38 Segment Bar Graph
- Dual Display (digits & bar graph)
- Capacitance Function, Transistor & Diode Test
- Frequency Range & Temperature
- RS232C Standard Interface
- Data Hold

Item# CSI345 **SALE $29.95**

Details at Web Site

> Test Equipment > Digital Multimeters/World Beater Prices

SONY Super HAD CCD B/W Weatherproof IR Camera

- Day & Night Auto Switch
- Signal System: EIA
- Image Sensor: 1/3" **SONY Super HAD CCD**
- Horizontal Resolution: 420TV lines
- Min. Illumination: 0Lux

Item# VC-317D: **$59.50**

SONY Super HAD CCD Color Camera

- Weather Proof
- Signal System: NTSC
- Image Sensor: 1/4" SONY Super HAD CCD
- Horizontal Resolution: 420TV lines
- Min. Illumination: 1Lux/F1.2

Item# VC-805: **$53.95**

SONY Super HAD CCD Color Weatherproof IR Camera

- Day & Night Auto Switch
- Signal System: NTSC
- Image Sensor: 1/4" **SONY Super HAD CCD**
- Horizontal Resolution: 420TV lines
- Min. Illumination: 0Lux

Item# VC-819D: **$62.50**

Details at Web Site

> Miniature Cameras(Board,Bullet,Mini's, B/W, Color)

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